Physics
M

HIGH SCHOOL

PHYSICAL SCIENCE

PART I.

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PHYSICAL SCIENCE.

CHAPTER I.

MEASUREMENTS.

I.—General Principles of Measurement.

Experiment 1.

Fig. 1.

Mark off on the edge of a piece of paper a distance equal to the length of the line A B (Fig. 1).

Experiment 2.

Draw a line the length of the distance laid off on the edge of the paper.

Which of your senses do you use in determining the equality of the lengths?

Experiment 3.

Lay the edge of the paper with the length A B marked off on it alongside C D and by moving it along thus:

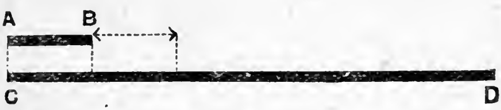


Fig. 2.

find how many times the length of C D contains that of A B.

How many times would the length of C D contain that of A B if A B were (*a*) one-half, (*b*) one-third, (*c*) three-fourths its present length?

Experiment 4.

Determine how many times the length of A contains that of B.

Fig. 3.

Experiment 5.

From Figure 4 the length of A is seen to be three times that of B with a part of A remaining; find by comparing the lines how many times the length of B contains that of the remaining part of A.

Fig. 4.

How many times then is the length of A that of B?

Experiment 6.

Find how many times the length of your desk contains that of your lead pencil.

1. Quantity.

That which can be expressed as so many times, or such a fraction of, another of the **same kind** is a **quantity.** For example, the length of each line in the above figures is a quantity, because the length of each is a certain number of times that of any other.

2. Measurement.

The measurement of a quantity consists in comparing it with another of the same kind to determine how many times the one is contained in, or how many times it must be taken to make up, one equal to the other.

3. Measure of a Quantity.

The measure of a quantity is the NUMBER expressing how many times the quantity contains another of the same kind assumed as a unit.

The complete expression of a physical quantity, therefore, consists of two parts :

(1.) The **number** indicating how many times the quantity measured contains the unit.

(2.) The **name, symbol,** or **description** of the unit with which the quantity is compared.

For example, we say a certain distance is 10 feet; a surface, 5 square inches; a volume, 8 cubic feet; and a mass, 3 pounds.

1. Give fully your expression of the length of

C D,	Experiment	3	above.
A,	"	4	"
A,	"	5	"
The desk,	"	6	"

2. What is the **measure** of each of the above quantities?

4. Units.

Since a quantity is measured by comparing it with another of the same kind, **any one quantity** may be used as a unit quantity by which another **like quantity** is measured; but that any system of measurements may be useful for purposes of intercommunication a limited number of units, with which all who are to use them are familiar, must be chosen. Hence it is that most nations legalize systems of units for common use.

5. Standards.

A unit which has been legalized by statute or common use is called a **standard.** Thus in Great Britain the national standard of length is the yard, which is defined by Act of Parliament to be the distance between two parallel lines on two gold studs in a particular bronze bar, the distance being measured when the temperature of the bar is 62° Fahr.

1. Why must the distance between the lines be measured at a set temperature ?

2. Why do nations preserve carefully copies of their standards of measurements ?

6. Metric System of Measurements.

By general agreement, what is termed the Metric System of Measurements has been adopted in most countries for scientific use.

It has also been adopted generally on the continent of Europe for the ordinary purposes of commerce.

II.—Metric Measurement of Length.

7. The Unit.

The standard is the **metre.** When adopted it was believed to be the one ten-millionth part of a quarter of the earth's circumference measured from pole to pole through Paris. In reality, it is an arbitrary standard, the distance between two lines on a platino-iridium bar, at the temperature of melting ice.

8. Subdivisions of the Metre.

The metre is subdivided into decimal parts:

Decimetre	(dm)	Latin	*decem,* ten	$= \frac{1}{10}$ or	·1 **metre** (m)
Centimetre	(cm)	"	*centum,* hundred	$= \frac{1}{100}$ or	·01 **metre**
Millimetre	(mm)	"	*mille,* thousand	$= \frac{1}{1000}$ or	·001 **metre**

That is:

1 metre	=	**10 decimetres**	=	**100 centimetres**	=	**1000 millimetres**
		1 decimetre	=	**10 centimetres**	=	**100 millimetres**
				1 centimetre	=	**10 millimetres**

Or,

1 millimetre = ·1 centimetre = ·01 decimetre = ·001 metre.

9. Multiples of the Metre.

The multiples of the metre are:

Decametre	(Dm)	Greek	*deka,* ten	= 10 **metres**
Hectometre	(Hm)	"	*hekaton,* hundred	= 100 **metres**
Kilometre	(Km)	"	*chilioi,* thousand	= 1000 **metres**

10. English Equivalents.

	In Inches.	In Feet.	In Yards.
Metre	39·37079	3·2808992	1·0936331
Decimetre	3·93708	·3280899	·1093633
Centimetre	·39371	·032809	·0109363
Millimetre.....	·03937	·0032809	·0010936

1 inch = 2·539954 centimetres.
1 foot = 3·0479449 decimetres.
1 yard = ·91438348 metres.

11. Approximate Values:

Metre = 39·37 inches; a yard and one-tenth.
Centimetre = $\frac{2}{5}$ of an inch.
Inch = 25·4 millimetres.
Kilometre = $\frac{5}{8}$ of a mile.

12. Denominations Most Commonly Used.

The denominations most commonly used are:

Kilometre, used much as we use the mile for measuring long distances.

Metre, used where we use the foot and the yard.

Centimetre, used as the unit of length in scientific physical measurements.

Millimetre, used in measuring short lengths, such as the diameter of a wire, the thickness of a thin sheet, etc.

QUESTIONS.

1. Reduce

Km	m	cm	mm
5,	3,	5,	2,

to millimetres, to centimetres, to metres, to kilometres.

2. Give a simple rule for changing from one denomination to another.

3. Why is the metric system convenient?

4. How many metres in 125·3 cm., 2·34 mm., 53·65 dm., 8·567 Km.?

5. How many centimetres in 3·45 m., 256 mm., 3·6 Km.?

6. How many kilometres in 3·4 m., 5·6 mm., 37·8 cm.?

7. How many millimetres in 31·6 m., ·85 cm., 9 3 Km.?

8. The measure of a certain length is 35 when the metre is the unit of length, what would be its measure if the centimetre were the unit ?

13. Scale.

The method employed in the experiments, pages 1 and 2, of measuring by constantly repeating the standard, would be found to be too slow and too inaccurate for general use. For more rapid and accurate measurements a **scale** or **rule** is used. This consists of a bar, generally wood or steel, on which is laid off the unit, its subdivisions and multiples. The length of the scale and the number of subdivisons of the unit will depend on the purposes for which it is to be used. Metric rules are generally graduated to millimetres. Fig. 5 shows a metric scale one decimetre in length.

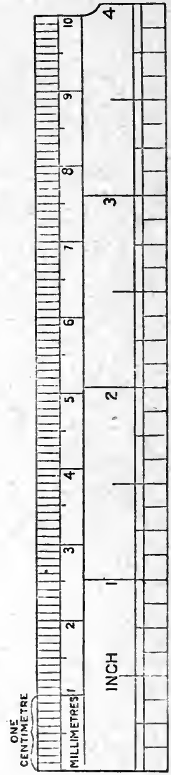


Fig. 5.

14. Method of Using a Scale.

The accuracy of the result in measuring with a scale will depend upon the care with which the length to be measured is compared with the scale.

Since the observer has to depend on his eyesight, he must be careful so to conduct his observations that the coincidence of the marks shall be real and not imaginary.

That no error may arise from the thickness of the scale, thus—

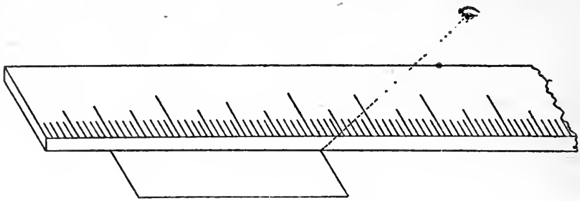


Fig. 6.

it should be placed on edge so that the graduation marks may touch the surface on which the measurement is made. Thus:

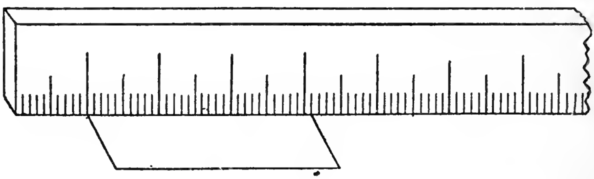


Fig. 7.

On account of the wearing off of the graduation marks at the ends of the scale, it is well to begin at a division at a distance from the end (Fig. 7).

Although metric rules are usually graduated only to millimetres, practice will enable one to estimate to the tenth of a millimetre by an imaginary division of a millimetre into ten equal parts.

Give the lengths of A B, A C and A D (Fig. 8) in centimetres to two decimal places.

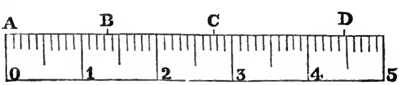


Fig. 8.

15. Experiments in the Measurement of Length.

1. Measure the length and the width of this page. Express the result in centimetres.

2. Measure the length of a foot rule in centimetres. From your measurement calculate the equivalent of an inch in centimetres.

3. Measure the distance between the points A and B (Fig. 9).

A X   X B

FIG. 9.

Estimate to the tenth of a millimetre.

4. Make a drawing of the top of your laboratory table on a scale of one-twentieth.

What are the dimensions of the drawing in centimetres?

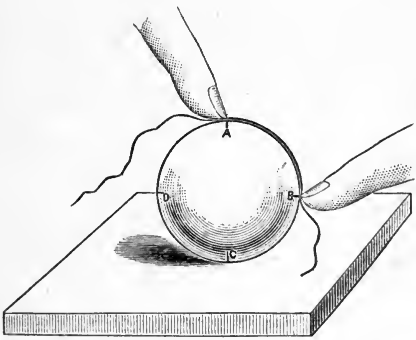


FIG. 10.

5. Draw a horizontal line A B 2·7 cm. long, and from B a vertical line B C, 3·6 cm. long. Measure the distance A C.

6. Estimate with your eye the length of your pencil in centimetres. Verify the result by the use of a scale.

Do the same with the lengths of several other objects which you believe to be not more than 15 cm. long.

7. Estimate the length and width of your class room in metres. Verify the result.

8. Measure the lengths of the curves A, B and C (Fig. 11) by finding the lengths of pieces of thread that will coincide with the lines, as shown in Fig. 10.

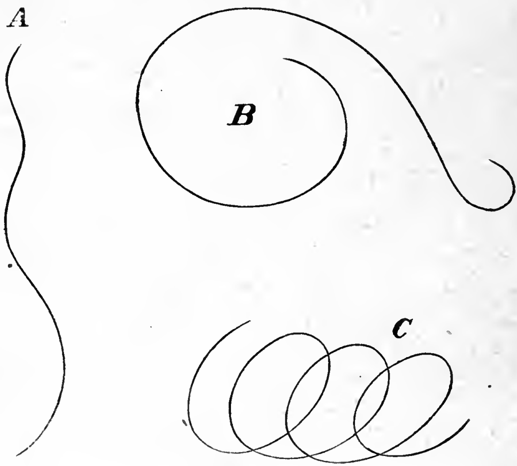


FIG. 11.

10. By means of a piece of thread, find the circumference of a one-cent piece.

11. Find the circumference of a one-cent piece by marking a point on it with ink, rolling it along a straight line drawn on paper, and measuring the distance between any two consecutive marks made by the ink.

What is the mean of this result and that obtained in Experiment 10?

12. Measure the diameter of a one-cent piece by placing it between the upright faces of two rectangular blocks and using the scale as shown in Fig. 12

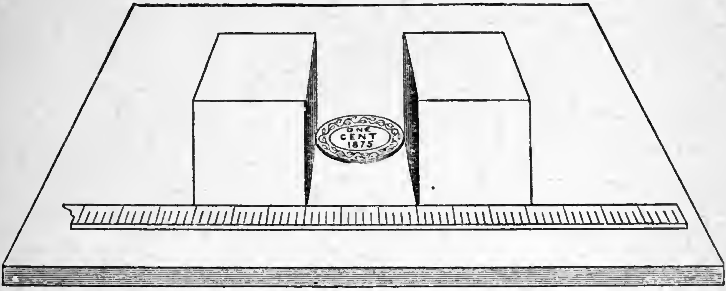


FIG. 12.

Find the ratio of the circumference to the diameter of a circle by comparing the result obtained in this experiment with the mean of those obtained in Experiments 10 and 11.

If the correct result is, the circumference is 3·1416 times the diameter, what is your percentage of error?

13. Measure the diameter of any small sphere—a wooden ball or a large marble—with the blocks used in Experiment 12 Thus:

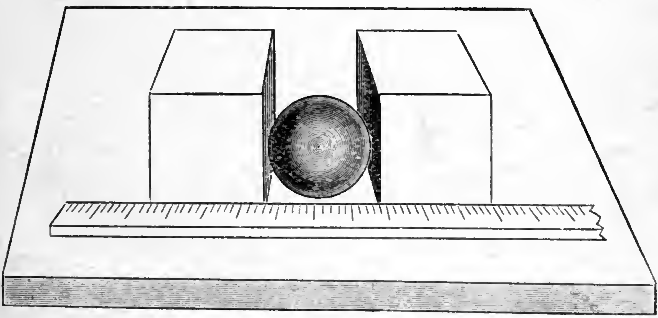


FIG. 13

Take the mean of the measurements of several diameters.

14. Measure by means of a strip of paper the circumference of the same sphere.

Obtain the diameter by dividing the circumference by 3·1416, and compare this result with that obtained in Experiment 13.

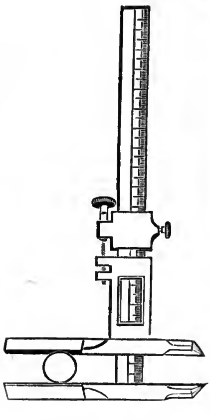


Fig. 14.

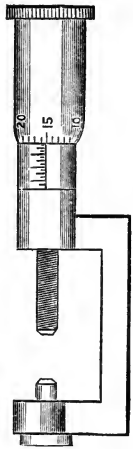


Fig. 15.

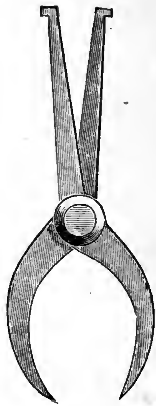


Fig. 16.

For practical purposes mechanics use instruments called calipers or guages for measuring the diameters of spheres, cylinders, etc. Figures 14, 15 and 16 show some common forms of these instruments.

III.—Metric Measurement of Surface.

15. Fundamental and Derived Units.

We have seen that in the measurement of length the unit employed is selected arbitrarily. Physical quantities are so related to one another that by choosing certain

elementary units all the others may be derived from these in virtue of those relations. The former are called **fundamental**, the latter **derived**, units.

17. Unit of Surface.

From the relation between length and surface, if a unit of length is assumed, a unit of surface may be derived from it. The most convenient unit of surface is a square, a side of which is the unit of length. For example, when the centimetre is taken as the unit of length the square centimetre (sq. cm.) is the unit of surface.

FIG. 17.

18. Measure of Surface.

The measure of any surface is, of course, the number of times the unit surface must be repeated to cover it.

QUESTIONS.

1. If a side of a square is one decimetre, how many surface units will be required to cover it, the unit surface being the square centimetre? Observe Fig. 18.

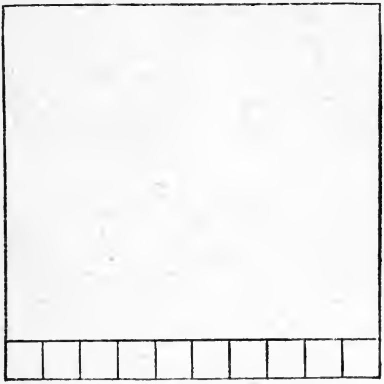


FIG 18—SQUARE DECIMETRE (½ SIZE).

2. Can the unit of surface be in any other forms than that of a square?

3. Draw on the blackboard a square, a side of which is one metre.

By drawing lines as in Fig. 18, divide it into square decimetres. How many are there of them?

4. Draw on paper a square centimetre. By dividing it by lines show how many square millimetres it contains.

5. From the answers to 3, 4 and 5, fill up the blanks in the following tables :—

1 square metre = ...sq. dm. = ...sq. cm. = ...sq. mm.

1 square millimetre = ...sq. cm. = ...sq. dm. = ... sq. mm.

6. The surface of a book measures 35·5 sq. cm., what is its measure in sq. metres?

7. A surface measures 5·5 when the square metre is the unit of surface, what will it measure if the square kilometre is the unit

8. How many square metres in ·01 sq. mm., 1·3 sq. Km., 3·5 sq. cm.?

9. How many square centimetres in 25·45 sq. m., 3·01 sq. mm.

10. The area of a figure is 10 when a decimetre is the unit of length. What is its area when a metre is the unit of length?

19. Experiments in the Measurements of Surface.

The following relations between the measures of surfaces and the measures of their lineal dimensions are assumed.

A **square,** the side of which has a **units of length,** contains a^2 **units of surface.**

A **rectangle,** the sides of which have a and b **units of length,** contains ab **units of area.**

A **triangle,** of which the base is a and the vertical height b **units of length,** contains $\frac{1}{2}\,ab$ **units of area.**

A **circle**, the radius of which has r **units of length**, contains πr^2 **units of area**.

A **sphere**, whose radius is r **units of length**, has a **surface** containing $4\pi r^2$ **units of area**.

1. Find the surface of this page in square centimetres.

What would be the side of a square of the same area ?

2. By means of a scale and a pair of compasses, draw on paper a triangle of which the sides are 3·9, 5·2 and 6·5 cm. Taking the longest side as base, measure the vertical height and determine the area of the triangle.

3. Determine the surface of one face of a ten-cent piece. Give the result in sq. mm.

4. By means of a scale and a pair of compasses, draw a square, a side of which is 6 cm. Inscribe in it a circle, and divide the square into square centimetres. Find the area of the circle by counting the number of squares inside the circle and estimating the areas of the incomplete squares. Compare the result with that obtained by the rule, **area** $= \pi r^2$.

5. Find the surface of any ball.

IV.—Metric Measurement of Volume.

The method of measuring **volume** is essentially the same as that employed in measuring **length** or **surface.** A volume is measured by comparing it with some other **quantity of the same kind**, that is with some other **volume**, taken as a unit. Its measure is the number of times it contains this volume, just as the measure of a certain **length** is the number of times it contains some **unit length**, and the measure of a **surface** the number of times it contains a **unit surface**.

20. Unit of Volume.

From the relation between length and volume, if a unit of length is assumed, a unit of volume may be derived from it. The most convenient is a volume in the form of a cube, an edge of which is the unit of length. For example, when the unit of length is the centimetre, the unit of volume is the cubic centimetre c.cm.

QUESTIONS.

1. Is the unit of volume a **fundamental** or a **derived** unit?

2. Can the unit of volume be in any other form than that of a cube?

3. Why is a cube a convenient form?

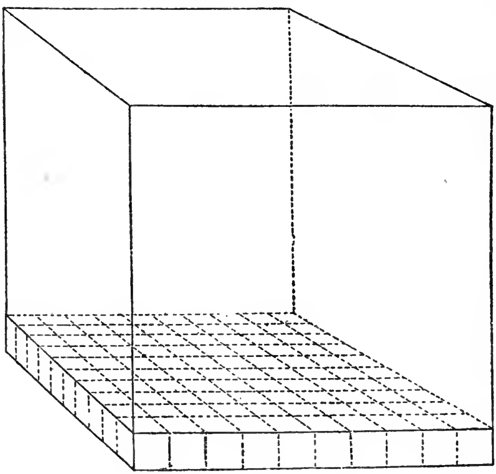


FIG. 19.—Cubic Decimetre ($\frac{1}{8}$ size).

4. How many cubic centimetres in a cubic decimetre? Observe Fig. 19.

5. Construct diagrams to show (*a*) the number of cubic decimetres in a cubic metre, (*b*) the number of cubic millimetres in a cubic centimetre.

6. From the answers to 4 and 5 fill in the blanks in the following table :—

1 **cubic metre** = ...c.dm. = ...c.cm. = ...c.mm.

1 **cubic millimetre** = . c.cm. = ...c.dm. = ...c.m.

7. How many cubic centimetres in 531·56 c.m., 235·78 c.mm. ?

8. If the measure of a volume is 5324·56 when the cubic centimetre is the unit of volume, what would be its measure if the cubic metre were the unit ?

9. How many cubic millimetres in 50·23 c.cm., 32·75 c. m. ?

10. A **litre** is a cubic decimetre. How many (*a*) cubic centimetres, (*b*) cubic metres does it contain ?

11. What is the **measure** of a litre when 5 cm. is the unit of length ?

21. Experiments in the Measurement of Volume.

The following relations between the measures of solids and the measures of their lineal dimensions are assumed :

A **cube**, the edge of which has a **units of length,** contains a^3 **units of volume.**

A **rectangular bar,** of which the edges are respectively a, b and c **units of length,** contains abc **units of volume.**

A **cylinder,** the height and radius of which have h and r **units of length** respectively, contains $\pi r^2 h$ **units of volume.**

A **sphere,** the radius of which has r **units of length,** contains $\frac{4}{3}\pi r^3$ **units of volume.**

1. Make of wood a cube, an edge of which is 1 cm.

2. Make of wood a litre block, that is, a cube the edge of which is one decimetre.

How many cubic centimetres does it contain?

3. Find the internal volume of a crayon box.

4. Determine, by measuring its depth and its diameter, the capacity of any cylindrical vessel. Give the result in cubic centimetres.

5. Find the volume of any spherical ball.

6. Make a rectangular prism of hard wood, 1 sq. cm. in section and 15 cm. long. Graduate one of the longest sides in centimetres. (Fig. 20).

FIG. 20.

What is the volume of the bar between any two consecutive division marks?

8. Take a tube of the form A, shown in Fig. 21, to which is attached a rubber tube and clamp. Place it in a vertical position in a holder and partially fill it with water. Mark the position of the surface of the water by making a fine line on the glass with a sharp file. Place the graduated bar in the tube with the first division of it immersed in the water. Mark the position of the surface of the water. Immerse another division and again mark the position of the surface. Continue until the whole upper part of the tube is graduated.

1. What is the volume of the water displaced by one division of the bar?

2. What is the internal volume of the tube between any two consecutive division marks?

9. After it has been graduated, fill the tube A (Fig. 21) with water, and under it place a small test-tube B. Regulating the flow by the clamp, let the water pass slowly from A to B, stopping the flow whenever one division of A has been emptied, and marking the position of the surface of the water in B. Continue until the tube B is graduated.

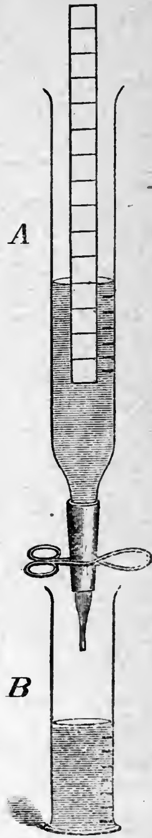


Fig. 21.

What is the internal volume of the tube B between any two consecutive graduation marks?

A graduated tube like A, Fig. 21, or that in Fig. 22, is called a **burette**, and a measuring cylinder like B, Fig. 21, or that in Fig. 23, a **graduate**.

Fig. 22.

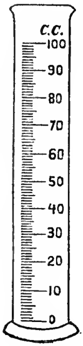


Fig. 23.

These are of various sizes and degrees of graduation, depending on the purposes for which they are to be used.

In using a burette be careful to see,

(1) That the burette is held in a vertical position.

(2) That the reading is taken from the position of the centre of the curved surface as seen when the eye is **level** with it (Fig. 24).

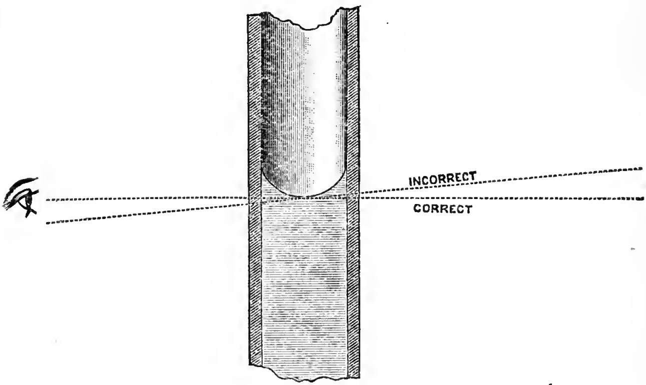


Fig. 24.

10. With a standard burette or graduate measure the volume of water between any two graduation marks on the tubes A and B (Fig. 21).

11. Run 10·5 c.cm. of water from a burette into a graduate.

Does the graduate indicate the same volume?

12. Measure the internal volume of a small bottle by filling it with water and measuring the volume of the water (*a*) with a burette, (*b*) with a graduate. Compare the results.

13. Measure with a burette 100 c.cm. of water, and pour it into a small Florence flask that will just contain it. Mark on the neck of the flask the position of the surface of the water.

14. Use the flask prepared in Experiment 13 to make (*a*) a 500 c.cm. flask, (*b*) a litre flask.

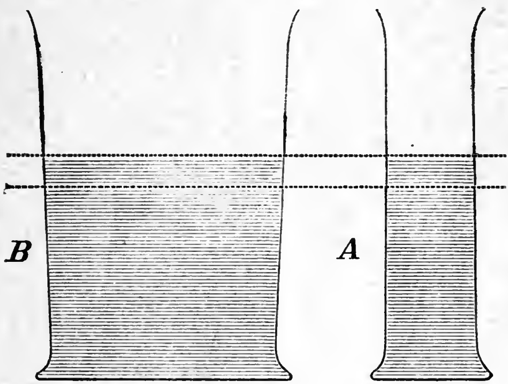


FIG. 25.

15. Determine the volume of water required to raise by one centimetre the levels of water contained in a beaker and in a test-tube. (Fig. 25).

1. What is the ratio of the area of the surface of the water in the beaker to the area of the surface of the water in the tube?

2. What would be the area of the surface of the water in a tube, if one centimetre **in length** on a tube indicated 1 c.cm. **of volume**?

3. With which can the volume of a liquid be measured with the greater accuracy, a narrow graduated vessel like A (Fig. 25), or a wide one like B? Why?

16. Obtain the volume of an irregular solid, for example a pebble, by placing it in a narrow graduated tube containing water, and noting the volume of water it displaces.

How could you obtain by a similar method the volume of a solid lighter than water?

CHAPTER II.

MATTER.

I.—Matter and Energy.

Our knowledge of the phenomena of the external world is derived through the medium of our senses. An extended study of these phenomena leads to the belief that the sensible universe is made up of but two things, or entities, **matter** and **energy.**

It is difficult to give precise definitions of these terms. Energy will be treated of in another chapter. In a general way, **matter may be defined as that which occupies space.**

From this description we recognize at once wood, iron, water and other solid and liquid bodies as matter.

1. Is a Gas, Like Air, Matter?

Experiment.

To answer this question, take a clear glass tumbler filled with air, and, holding it in a vertical position with bottom upwards, push it down into water. (Fig. 26).

1. Does the water fill the tumbler?

2. Does the air occupy space?

3. Is it matter?

Fig. 26.

2. Substance, Body, Mass.

Our most superficial observations show us that matter differs in kind and varies in quantity. Water differs from stone, sugar from salt, and air from ammonia.

A **definite kind** of matter is called a **substance,** and a **definite portion** of matter, **a body.**

The quantity of matter in a body is called its mass.

II.—States of Matter.

Experiment 1.

Take any solid body, such as a piece of wood or iron, lift it and place it on the table.

1. Does the whole move when a part moves ?
2. Is its shape changed ?
3. What is necessary to change its shape ?

3. Solid.

A solid is a body that possesses rigidity, that is the power to resist change of shape.

Experiment 2.

Put your fingers into a vessel containing water and try to lift the water out. With a spoon dip the water out of one vessel and place it in another of a different shape. Pour water on a horizontal surface. Try to grasp a handful of air.

1. Is the whole of the water lifted out when a part is raised ?
2. Has it a definite shape of its own ?
3. What shape does it take ?
4. Can you lift a piece of air and carry it from one point to another ? Has any portion of air a shape of its own ?

Water and air belong to the class of bodies known as Fluids.

4. Fluid.

A fluid is a body which possesses no rigidity whatever, but which is deformed by the action of any force, however small.

Experiment 3.

Take a glass tube (Fig. 27) closed at one end, fill it nearly full of water or any other liquid, insert a piston and push in on it.

Is there any change in the volume of the liquid ?

FIG. 27.

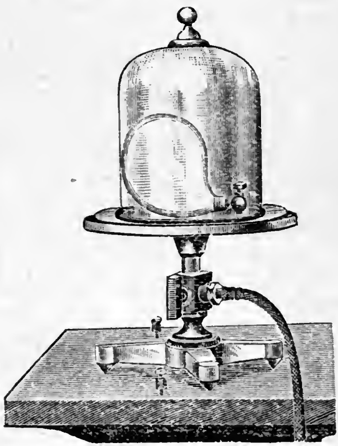


FIG. 28.

Experiment 4.

Repeat Experiment 3, having the tube filled with air instead of water.

1. What change takes place in the volume of the air ?
2. What causes the change ?

Experiment 5.

Place an elastic rubber balloon partially filled with air under the receiver of an air pump (Fig. 28). Exhaust the air from the receiver.

1. What change in the volume of the air in the balloon takes place?

2. How did removing the air from the receiver affect the pressure to which the balloon is subjected?

3. What caused the change in the volume of the air in the balloon?

5. Liquid—Gas.

On the basis of compressibility and expansibility fluids are divided into two classes, **liquids** and **gases.**

A liquid is a highly incompressible fluid, that is, it is a body which possesses a definite volume but no definite shape, moulding itself into the shape of the containing vessel.

A gas is a compressible and expansible fluid, that is, it is a body which possesses neither definite shape nor definite volume, taking not only the shape but also the volume of the containing vessel.

6. How Does a Powder like Flour or Sand Differ from a Liquid?

Experiment 6.

To answer this question, pour some of it on a horizontal table.

Does it behave as the water did (Experiment 2)?

Look at the powder on the table through a magnifying glass.

What appearance has it? How does it differ from, and how resemble, a heap of stones?

7. Fact—Theory.

Experiments lead to the establishing of facts. To explain these facts theories are proposed. A theory is an imagined cause which is sufficient to account for a fact. It should be clearly distinguished from the fact of which it is the supposed explanation. It is not the statement of anything established by investigation, but simply a possible or probable explanation of some observed phenomenon. It may or may not be true. The simpler it is, and the greater the variety of phenomena it is capable of explaining, the greater is the probability of its truth.

III.—Constitution of Matter—Molecular Theory.

We have shown that matter exists in different states.

The molecular theory of the constitution of matter is offered as an explanation of this and numerous other facts connected with matter. It may be thus stated:

1. *Matter is not continuous, but is built up of extremely minute parts, called* **molecules**. *The molecules are so small that the most minute particle of matter visible under the most powerful microscope, contains at least two millions of them* (MAXWELL).

2. *The molecule is the smallest quantity of any substance which can exhibit the properties by which that substance is identified.*

3. *All molecules of the same substance are alike, but those of different substances are different.*

4. *Molecules are not in permanent contact with one another, but are separated by intermolecular spaces which are often large as compared with the molecules themselves.*

5. *The molecules have a rapid to-and-fro motion and are constantly striking their neighbours and rebounding from them, thus keeping open the spaces between them.*

3. Molecular Conditions of the States of Matter.

In each of the states the molecules are in active vibratory, or to-and-fro, motion.

In solids the molecules are not supposed to move from place to place through the body, but each has, relatively to the others, a definite position in which it moves.

In fluids the molecules are free to move from any one part of the mass to any other, and in consequence liquids and gases take easily the shapes of the vessels in which they are placed.

In liquids the molecules are not so free to move as in gases. They simply glide around among one another, encountering and jostling those near them; while in gases, since the intermolecular spaces are larger, they have periods of free motion and appear to be in a continual state of repulsion. Hence gases are compressible and expansible, while liquids are practically incompressible.

CHAPTER III.

MOTION.

1. Position.

1. Describe the position of the town of Barrie.

2. Can you describe its position without reference to some other point?

3. Can you do so without making use of distance and direction?

4. Describe accurately and in several ways the position of the point A on this page.

× A

From considerations such as the foregoing it becomes evident that we cannot even think of the **absolute** position of a body (*i.e.*, of its position without reference to any other body). Hence we say that position is only **relative.** We also see that position involves the simple notions of **distance** and **direction.** Thus **the position of A with respect to B may be made clear by stating the distance of A from B, and the direction of A from B.**

2. Motion.

1. What do you mean by saying that a railway train is in motion?

2. What would you mean by saying that one passenger in that train is moving about while another passenger is at rest?

3. Are the seats in the railway coach moving? With respect to what are the seats moving?

4. With respect to what are they at rest? Is the earth at rest?

From the answers to the above questions it appears that **motion, like position, is relative.** We say that **A is moving relatively to B when the position of A with respect to B is changing continuously.**

We often speak of the motion of one body without mentioning another body. In such a case the body not mentioned is easily understood. Give examples of this.

3. Velocity.

Often we have occasion to consider not only the total change of position which a body undergoes, but also the length of time during which this change of position takes place.

A train moves from Montreal to Toronto, 333 miles, in 9 hours.

1. What is its average speed or velocity?

2. When you say that the velocity of this train is 37 miles per hour, what velocity are you using as a unit in terms of which to express the velocity of the train?

3. What unit are you using when you say that this same velocity is 3,256 feet per minute?

4. Is your unit velocity a fundamental unit or a derived unit?

5. If the latter, from what is it derived?

6. How many rods does the above train move in one minute? How many yards in one second?

7. Describe the train's speed in terms of the unit derived from (*a*) the rod and the minute, (*b*) the yard and the second, (*c*) the foot and the second.

A particle moves a distance of 16·42m. in 4 seconds. Describe its average speed in terms of each of the following units :—(*a*) One metre per second ; (*b*) one centimetre per second ; (*c*) one centimetre per minute ; (*d*) one centimetre per second.

The velocity of a particle is the time-rate at which it is moving, and the measure of the average velocity during a given interval is obtained by dividing the measure of the distance traversed during that interval by the measure of the interval.

If you divide the measure of the distance in feet by the measure of the interval in seconds the quotient is the measure of the speed in terms of what unit?

Experiment 1.

Suspend a weight by means of a wire or a strong cord (Fig. 29). Make the distance from the point of suspension to the centre of the weight 993 mm. This will serve as a pendulum, and will swing in a period of one second approximately. Prepare a straight, stiff plank about three metres long. On one side fasten lengthwise two narrow strips (as in Fig. 30). Place the plank on a table with this side upward and with one end enough higher than the other to cause a marble to roll down the channel between the two strips readily but not too rapidly. Set the pendulum swinging, and while A is counting the swings aloud, let B hold a marble at a marked point near the higher end of the board. When A says one, B should set the marble

Fig. 29.

Fig. 30.

free, but follow it with his hand, in which he should hold a

piece of chalk. As A says two, three, four, etc., B should make a mark on the board at the point at which the marble is at that instant.

With a graduated ruler or tape determine the distance traversed by the marble during the following intervals: (*a*) 1st second, (*b*) 2nd second, (*c*) 3rd second, (*d*) 1st and 2nd seconds, (*e*) 2nd and 3rd seconds, (*f*) 1st, 2nd and 3rd seconds, etc.

1. Find the average speed during each of the foregoing intervals.

2. Carefully compare the average speeds in the first three cases.

3. Describe in your own way, as fully as you can, the motion of the marble along the plank.

4. Give other examples of bodies moving at changing speed.

4. Velocity of a Particle at a Given Instant.

If the motion of a body is not changing, it is obvious that its average velocity during any interval is its actual velocity at any instant of that interval.

1. If the motion of a body is changing, how would you approximately determine its velocity at a given instant?

For example, how would you ascertain the speed of a railway train at the moment it passes a given point on the track?

2. With the apparatus described above, find approximately the speed of the marble (*a*) at the middle of the 1st second, (*b*) at the middle of the 2nd second, (*c*) at the middle of the 3rd second.

If a body is moving with a varying speed its actual speed at a given instant may be defined as the average speed during an infinitely short interval containing that instant.

5. Acceleration.

If the motion of a particle is changing, the particle is said to be accelerated positively or negatively, according as its velocity is increasing or diminishing.

1. At one instant the velocity of a railway train is 40 miles per hour, 80 minutes later its velocity is 30 miles per hour. How much has its velocity changed during the whole interval?

2. How much, on the average, during each minute?

3. How much during one hour?

4. Describe fully the change per minute in the velocity of this train.

5. Describe the change in the velocity of the marble as it rolls down the plank in the experiment above.

Rate of change of velocity is called acceleration.

1. In answering question 4 above, what unit of acceleration did you use?

2. Answer the same question, using another unit.

3. Is your unit fundamental or derived?

4. If the latter, from what is it derived?

6. Uniform Acceleration.

If the velocity of a body is increasing or decreasing by equal amounts in all equal intervals of time, its acceleration is said to be uniform.

When the acceleration is uniform the average velocity during any interval is the actual velocity at the middle instant of that interval, and hence is equal to half the sum of the initial and the final velocities.

QUESTIONS.

1. A particle moving with uniform acceleration has a velocity of 10 cm. per second, and 10 seconds afterwards has a velocity of 20 cm. per second. What is the acceleration in cm. per second per second?

2. A particle moving with uniform acceleration has a velocity of 10 feet per second at the beginning of a minute, and a velocity of 30 feet per second at the end of the minute. What is its average velocity during the minute? How far does it move during the minute? What is the acceleration?

3. A particle starting from rest is accelerated 2 feet per second per second. What is its velocity at the end of 5 seconds? How far does it move during the 5 seconds?

4. A particle which is uniformly accelerated has at the beginning of a minute a velocity of 10 feet per minute, and at the end a velocity of 10 feet per second. What is its acceleration? What is its average velocity? How far does it go during the minute?

5. A body starting with a velocity of 10 cm. per second is accelerated 5 cm. per second per second. How far does it go during one minute? What is its final velocity?

CHAPTER IV.

ENERGY AND WORK.

The terms energy and work are used in physics in much the same sense as in every-day speech.

1. Energy.

1. What is meant by the statement that a man possesses much energy ?

2. Can anything except man possess energy ?

3. Can inanimate objects possess energy ?

4. What would you accept as evidence that a body possesses energy ?

5. Mention examples of bodies possessing energy.

Energy is capacity for doing work.

2. Work.

Let us consider the nature of work. If you throw a cricket ball you do work on the ball.

1. During what time are you doing this work ?

2. What is being done to the ball during this time ?

A careful study of the subject leads to the belief that **whenever a portion of matter does work it accelerates the motion of other portion of matter.** Often this acceleration is not so obvious as in the example given above. For example, if a lump of lead is laid on an anvil and is struck with a hammer the motion of the lead as a whole is not accelerated, but we have reasons

(to be spoken of hereafter) for thinking that the molecules of the lead have their motions accelerated. Again, if a body, say a pound weight, is lifted at a **uniform speed** vertically, work is certainly done, yet there is no **acceleration** of the body as a whole, nor have we reason to suppose that its particles are made to vibrate any more rapidly. Here it is supposed that the work done on the pound weight is not stored up in the pound weight itself, but is passed on to whatever that energy may be which causes gravitation. The pound weight, however, is now ready to receive this energy at any time, and hence is said to possess **potential energy**.

Experiment 1.

Take the plank used in Experiment 1, page 31, and two glass spheres an inch or more in diameter (large marbles will answer). Elevate one end of the plank so that if one of the spheres is very gently started to roll down the plank it will not stop, but do not elevate it enough to cause it to start from rest. Call the spheres A and B.

Start A down the plank and send B after it at a greater velocity. Observe what takes place when B overtakes A.

1. How is B's velocity changed?
2. How is A's velocity changed?
3. Which sphere has work done upon it?
4. What body does the work?
5. What change which you can observe takes place in the body doing the work?

6. Can B do work on A (*a*) when both are moving in the same direction and at the same speed? (*b*) when A and B are moving in opposite directions?

A study of the foregoing experiments leads to the conclusion that B can do work on A only when B has a velocity relatively to A.

A careful investigation of the subject leads to the general conclusion that **one portion of matter can do work on another only when the former has a velocity relatively to the latter.**

Sometimes this velocity is not obvious. For example, when steam does work on the piston of a steam engine, the motion of the body doing the work relatively to that receiving the work is not visible, but we have reasons for believing that the particles of the steam are moving relatively to the piston, and that the work is done by these particles, and not by the body of steam as a whole. Again, when a body is allowed to fall freely near the surface of the earth the motion of this body is accelerated, and hence work is evidently being done on it during its fall. In this case no body or bodies visible, or in any other way capable of being recognized by our senses, is doing work on the falling body; but it is against our experience, as well as our reason, to suppose that work can be done on a body except by something else. Hence we are forced to believe that the work in this case is done by that intangible something which causes gravity, and which doubtless is in motion relatively to the falling body. In short, we suppose that that which received the work

when the body was raised is now in turn doing work on the body while it is falling.

Experiment 2.

Repeat Experiment 1, substituting in place of B a sphere C having a greater mass.

Cause C to increase the speed of A by the same amount as in the first experiment, and carefully observe the change of velocity of C.

1. In which case is the velocity of the sphere doing the work reduced the more?

2. Is the same work done on A in both cases?

3. How does the energy of A, before work is done on it, compare with its energy afterwards?

4. If the sphere doing the work has the same initial velocity in both cases, in which case has it the greater capacity for doing work?

Such experiments as the foregoing, and our ordinary observations, indicate that **a body possesses energy in virtue of its mass and its velocity.** We also see that **when work is done on a body, that body possesses more energy than before, while the body doing the work possesses less energy than before.** In short, **energy is transferred from the body doing the work to that on which the work is done.**

3. Forms of Energy.

A body may possess energy in consequence of bodily onward motion, of which we have considered several examples. But, as has already been indicated, this is not the only condition under which a body may possess energy.

Experiment 3.

Fig. 31.

Strike a tuning fork on the table and immediately place the prongs so as just to touch the surface of some water (Fig. 31).

1. What evidence have you that the fork possesses energy ?

2. Is there any visible motion of the fork in this case ?

3. What is the nature of this motion ?

4. Mention other examples of similar motion ?

5. When the tuning fork is struck, what sensation is experienced by all within a moderate distance from the fork ?

6. Upon what part of the body is work done to produce this sensation ?

7. As the fork is not in contact with your ear, how can it do work on your ear ?

8. What is there between the fork and the drum of your ear ?

9. If this medium receives energy from the fork and transfers it to your ear, what is the condition of this medium while it possesses the energy ?

Experiment 4.

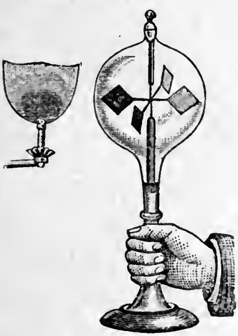


Fig. 32.

Place a radiometer near a hot body such as the flame of a gas burner or a red-hot metal ball (Fig. 32).

1. What evidence have you that work is being done on the radiometer ?

2. What is the result when the radiometer is exposed to the sun light ?

3. Is the sun in a position to do work **directly** on the radiometer ?

4. What must therefore possess the energy after it leaves the sun and before it is received by the radiometer ?

We are thus led to see that there are various forms of energy, all doubtless possessed by matter of some kind having some mode of motion.

1. **Energy of bodily onward motion.**

2. **Energy of bodily vibration.**

3. **Energy of molecular vibration, or heat.**

4. **Radiant energy,** or the energy possessed by the intangible medium called luminiferous ether, which we suppose to fill all space.

5. **The mysterious forms of energy which produce gravitation, chemical affinity, magnetic attraction, magnetic repulsion, etc.,** and which may be forms of radiant energy.

6. **The energy of the electric current,** which is well exhibited in the electric motor. This also is probably a form of radiant energy.

4. Potential Energy—Kinetic Energy.

When a body is in a position to be accelerated by energy of the form No. 5 above, as, for example, when a mass is raised above the surface of the earth, it is customary to say that this body possesses **potential energy.** Other examples of this kind are a piece of iron separated from a magnet; two substances such as coal and oxygen which have a tendency to chemically unite; the spring of a watch when wound up, etc. The raised weight, bent spring, etc., do not, strictly speaking, possess actual energy, but only the possibility of acquiring it whenever left free to move.

Since, however, the source whence they receive it is not apparent, it is customary to speak of them as if already possessing the energy which they have the power of acquiring. Actual energy, that is the energy possessed by a body in virtue of its mass and its velocity, is often called **kinetic energy.**

5. Transmutation of Energy.

When energy is changed, as it may be, from one form to another, we say that energy has been transformed or transmuted.

6. Conservation of Energy.

Careful experiments, which are quite beyond the limits of an elementary work, have led to the following general conclusion, which is now universally accepted.

In all transformations and transferences of energy no energy is created or destroyed. In short **the total of the energy of the universe is a constant quantity.**

This general conclusion is known as the **law of conservation of energy.**

7. Law of Nature.

When, as in the case above, from many observed facts a **general conclusion** is reached, this conclusion is called a **law of nature.**

8. Work more Fully Defined.

We may now more fully define work as the **transference or transformation of energy.**

QUESTIONS.

1. Why is a bullet of lead more destructive than one of cork would be ?

2. If one railway train runs into another from the rear when both are moving at nearly the same velocity, why is the damage much less than if the front train had been at rest ?

3. Under what conditions would the damage be even greater than in the second of the above cases ? Why ?

4. When the clapper strikes the bell what work is done, or in other words, what transference or transformation of energy takes place ?

5. If a leaden bullet is placed on an anvil and struck a violent blow with a hammer the flattened bullet is found to be quite hct. What transference and transformation of energy occurs ?

6. In the running of a steam railway train what form of energy is transformed into the energy of onward motion of the train ?

7. Why are bodies warmer in the sunshine than in the shade ?

8. What transformation of energy occurs in this case ?

CHAPTER V.

FORCE.

I.—Nature of Force.

1. Force—Acceleration.

In the preceding chapter we have considered energy and its transference and transformation. In connection with the transference of energy there arises a quantity of great importance which we shall next investigate.

We have seen in the experiments on the balls A and B (page 36), that when B does work on A the velocity of A is increased, while that of B is decreased, the increase of energy in A and the decrease of energy in B taking place during the brief interval of contact between the two bodies. While the balls are in contact we have an **action** of B on A, and a **reaction** of A on B. This action and reaction constitute what is called a **stress,** and each aspect of the stress considered by itself is called a **force.** In this case the force to which A is subject is a tendency to acceleration, while that to which B is subject is a tendency to retardation, that is, a tendency to negative acceleration. Hence either force is a **tendency to acceleration.**

2. Force—Energy.

In the above example the forces are produced by energy which we have no difficulty in recognizing. The modern view is that **force is always produced by energy,**

although in many cases the energy producing a force is by no means obvious.

Experiment 1.

Take an ordinary glass flask and close the neck, not too tightly, with a rubber stopper.

What is in the flask?

Place the flask over the flame of a spirit-lamp or of a Bunsen burner?

1. What is the result?

2. What change takes place in the **energy** of the contents of the flask while it is over the flame?

3. What evidence have you of the production of a **force**?

4. What **energy** acting on the stopper gives rise to this **force**?

5. Did the air in the flask possess any energy before the flask was placed over the flame?

6. Why did the stopper not move before the air within the flask was heated?

Experiment 2.

Arrange the flask as before, but instead of exposing it to a hot flame place it under the receiver of an air pump and exhaust the air from the space surrounding the flask.

What is the result?

1. What **energy** produces the **force** of which this result gives evidence?

2. Was this energy increased by working the air pump?

3. Why did the stopper not move before the pump was worked?

4. What was changed by working the pump?

5. Can a **force** (tendency to acceleration) exist where no apparent acceleration results?

6. If you have reason to know that a body is subject to a **force**, and that body is not apparently accelerated, what inference must you draw?

3. Counterbalancing Forces.

Experiment 3.

Hold any object in your hand a few feet above the table and let go your hold.

1. What evidence have you that this object is subject to a **force**?

2. Did this force exist before you let go your hold?

3. What evidence of its existence had you?

4. If while you were holding the body this force had instantly ceased to exist, what would have happened?

The tendency of a body to acceleration towards the earth is called the **weight** of the body.

Experiment 4.

Support at arm's length a mass of three or four pounds fastened to the end of a string, and while it and your arm are at rest let some one cut the string.

1. What happens to the mass? What happens to your hand and arm?

2. These results prove the existence of what **forces**?

3. Did these forces exist before the string was cut?

4. Were these forces changed by cutting the string?

5. What change, so far as forces are concerned, was produced by cutting the string?

From these observations it is seen that **a force may exist although no apparent acceleration occurs**, provided another force exists to counterbalance the first.

4. Recognition of a Force.

We have, so far, two ways of recognizing the existence of a force.

1. **By observing the resulting acceleration.**
2. **By showing that there is a counterbalancing force.**

II.—Manifestations of Force.

5. Elasticity.

Experiment 1.

Fasten a rubber band to a fixed point of support, and to the lower end attach a small piece of iron, or any other convenient object.

1. What is the result ?
2. What **tendency to acceleration** do you know is at all times present in the piece of iron ?
3. What is the direction of this tendency ?
4. How is it that when the iron is suspended as above it comes to rest, notwithstanding the existence of this force?
5. When the iron is at rest, what must be the direction and magnitude of the force exerted by the stretched band ?
6. If the band be stretched still further, what is the effect on the **force** which it exerts ?
7. What experiment proves your answer ?

Experiment 2.

Place a thick piece of soft rubber on the table and lay a heavy object upon it.

1. What **change** do you observe in the rubber ?
2. Is this piece of rubber exerting a force ?
3. How do you recognize the existence of this force ?
4. What are its magnitude and direction ?

These forces are said to be due to the **elasticity** of the rubber. In the first case it is called **elasticity of stretch** and in the second **elasticity of compression.** All solids exhibit the first, more or less, and some liquids. The second is exhibited by all solids, liquids, and gases.

Experiment 3.

Bend a slender rod of wood.

1. What evidence of the existence of force have you ?
2. What change of length takes place in the convex side ?
3. What in the concave side ?

Here we have a combination of elasticity of stretch and elasticity of compression. Twist the same rod of wood and we have an example of what is called **elasticity of torsion.** Doubtless all elasticity is of the same kind, and is due to some form of energy giving the particles of the strained body a tendency to return to the positions occupied by them before the strain. Of the nature of this energy we know nothing.

It will be observed that the word **strain** is used to denote **any definite alteration in the form or volume of an elastic body.** The student will also see that **if a strain is observed we have evidence of the existence of a force**, evidence indeed of the existence of two equal and opposite forces.

Let us next examine some manifestations of force less familiar than those already considered. Bear in mind that force is not an **objective reality**, like matter and energy, but only a **condition of matter** which is produced by the action of energy. Unfortunately force is often thought of by the unscientific as an objective reality, and

hence much confusion arises concerning it. When we come to the measurement of force we shall be able to see more clearly its true nature. At present we must be content to think of it as a **tendency to acceleration.** This definition is of course somewhat indefinite, but it is sound so far as it goes, and it will be made definite as soon as we are in a position to do so. The relation of force to change of motion is in some respects similar to that of velocity to change of position. Velocity might be indefinitely defined as the tendency of a body to change its position. A precise definition of velocity is time-rate of motion, that is, time-rate of change of position. When we have reached a precise definition of force it will be possible to see more clearly the similarity.

6. Electric Attraction and Repulsion.

In the following experiments particular attention is called to the fact that **at least two bodies are concerned in every force.** This fact is universal.

Experiment 4.

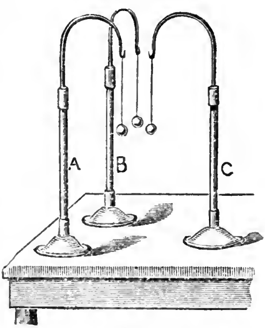


FIG. 33.

Suspend three pith balls from convenient supports, as shown in Fig. 33, using fine silk thread. Arrange the apparatus so that you may vary the distance between the balls. Call the balls A, B and C.

1. Touch the balls with your hand. Do you observe any tendency on the part of the balls to come together or to separate ?

2. Rub a piece of vulcanite briskly on a piece of silk or on your coat sleeve, and having moved B and C away, touch A with it, allowing the ball to roll over the rubbed surface so that all parts of its surface may come in contact with it. Now move B toward A, not allowing them to touch.

What do you observe?

Do you find **one** or **both** balls subject to a force?

3. Move B and C toward each other. Have you evidence of any unusual force?

4. Move C toward A, and what is the result?

5. Roll A in the fingers for a moment and again bring it near B and C.

What is the result?

In the above experiment A has been **electrified** by bringing it in contact with the rubbed vulcanite. We expended muscular energy in electrifiying the vulcanite, and hence some other form of energy must have resulted. The precise nature of this energy is not known, but we see that it can produce force.

Experiment 5.

Electrify both A and B and bring them near each other.

1. What is the result in this case?

2. Bring each separately near C, and what is the result?

3. How many bodies are concerned in any force of whose existence you have evidence?

4. Can you electrify C from A or B? Try.

5. What is the result when an electrified ball is rolled in the fingers?

7. Magnetic Attraction and Repulsion.

Experiment 6.

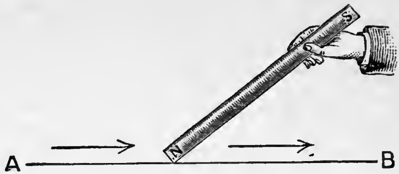


FIG. 34.

Magnetize three sewing needles by rubbing them in one direction with a strong magnet (Fig. 34). Suspend two of them by silk fibres, as shown in Fig. 35.

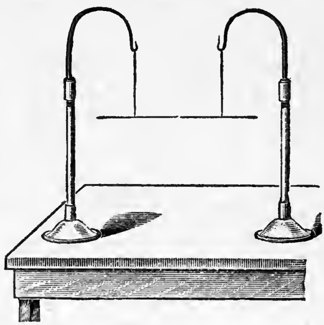


FIG. 35.

1. What position does each assume when left to itself at a considerable distance from the other? What is the result if it is disturbed?

2. What evidence have you that the needle is subject to one or more forces?

A magnetized needle suspended so that it is horizontal and is free to rotate about its point of support in a horizontal plane is called a **compass needle.** The end having a tendency to point toward the north is called the **north pole,** and the other end is called the **south pole.**

Experiment 7.

Take the remaining magnetized needle in your hand and hold, first one end and then the other, near the north pole of one of the suspended needles.

1. What results do you observe?

2. Of what forces have you evidence?

Repeat the experiment with the south pole of the suspended needle.

Experiment 8.

Place the two suspended needles so that the north pole of one shall be near the south pole of the other.

1. Do you find one or both needles subject to force?

2. What attractions or repulsions are observed when (*a*) like poles are brought near each other, (*b*) unlike poles?

Experiment 9.

Stretch, in a direction north and south, a wire through which an electric current is flowing, first above and then below a compass needle (Fig. 36).

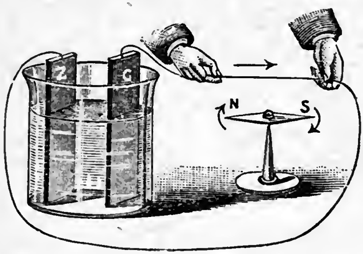


FIG. 36.

An electric current may be obtained by placing a copper and a zinc plate in a vessel containing dilute sulphuric acid in

the proportion of about ten parts of water to one of acid, and connecting them by a wire as shown in figure.

1. What is the result?

2. Are the poles of the magnet subject to forces? If so, in what direction do the forces act?

8. Molecular Attraction.

Experiment 10.

Sprinkle a few drops of water on a pane of glass and hold the pane in a horizontal plane with the wet side underneath.

1. What force do you know each drop of water is subject to?

2. Since the drop does not fall, of what other force have you evidence?

3. What inference regarding mutual attraction between particles of water must you draw from the fact that the drops of water remain entire?

4. Is mutual attraction confined to bodies of sensible (such as may be perceived by the senses) magnitude?

Experiment 11.

Heat two pieces of glass to redness and press the heated parts together. Allow them to cool and try to separate.

1. Of what force does the result furnish evidence?

2. Give other examples of similar phenomena.

Experiment 12.

Fold a sheet of tea-lead many times and subject it to very great pressure either in a vise or by hammering.

1. On examining the resulting lump, what evidence have you of the existence of mutual attraction between the particles of the lead?

2. Why are you able to make a mark on the blackboard with a piece of chalk ?

3. To what is the efficiency of glue due ?

From such experiments as the above we see that **there is mutual attraction between the molecules of bodies, which becomes very great when the particles are brought sufficiently close to one another.** This attraction is called **cohesion** or **adhesion,** according as the molecules are of the **same** or of **different substances.**

It is not supposed that the forces existing in a case of attraction or repulsion are inherent in the bodies themselves. We suppose these forces to be produced by some **unknown form of energy** existing in the medium surrounding the bodies.

III.—Production of Force by Energy.

9. Force—Work.

It is found that if a perfectly elastic ball is thrown against an immovable body the ball rebounds with the same velocity, and therefore with the same energy with which it strikes. Hence we see that no energy is expended in producing the force exerted on the immovable body during the moment of contact. If, however, the body struck is accelerated by the impact, the striking ball does lose energy. From such observations as the above we see that **the mere production of force does not require the expenditure of energy.** Energy is **expended** only when **acceleration results,** that is to say, only when **work is done.**

A good example of this is furnished in the pressure which a gas exerts on any surface with which it is in

contact (Experiment 1, page 44). This pressure is supposed to be due to the innumerable impacts of the molecules of the gas against the surface. If no work is done on the surface it is found that the gas loses no energy; but if work is done on the surface, for example, if the surface is heated (molecules accelerated), or accelerated bodily, it is found that the gas is cooled, that is, that it loses energy.

10. Modern View of Force.

The modern view that force is always produced by energy, rests on the following basis:—

1. This view is in strict accordance with the law of conservation of energy.

2. It is not inconsistent with any known fact, and many facts are more satisfactorily explained by this hypothesis than by any other.

It is, perhaps, in the case of the manifestation of force in connection with gravitation that it is most difficult to even imagine the nature of the energy which produces the force; but to imagine "action at a distance" is still more difficult, and, to some minds at least, is quite impossible.

11. Action of a Force.

Although we hold the foregoing view regarding force, we shall, as a matter of convenience and because the practice is almost universal, use the phrase action of a force in speaking of acceleration or other effects, such as compression, bending, stretch, etc., which are, strictly speaking, due to the action of energy.

CHAPTER VI.

MEASUREMENT OF MASS.

I.—Determination of Equal Masses.

1. Equal Masses.

We may define equal masses as masses on which the **same force**, acting separately, produces **equal accelerations.**

Experiment 1.

Arrange apparatus as shown in Fig. 37. The track should be about 10 feet long, as smooth as possible, and a perfect plane. The cart should be about five or six inches long and

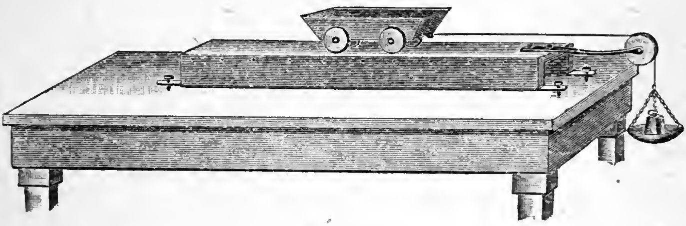


Fig. 37.

three or four inches wide, with well turned metal wheels two or three inches in diameter. The grooved metal pulley should be well turned and truly mounted, and the string should be parallel with the track.

Carefully oil the wheels and the pulley. Raise one end of the track until the cart will not stop if started, but do not raise it far enough to make the cart start itself. Now load the cart

with some heavy material, such as a large lump of lead, and place a much smaller mass in the scale pan. Arrange a pendulum, as in Experiment 1, p. 31, with which to measure time. As in that experiment, carefully mark on the board the distances the cart moves from rest in 1, 2, 3, 4, etc., seconds.

1. What is the force which produces the acceleration observed ?

2. Is any of this force required to overcome friction ?

3. What is the total mass accelerated in this experiment ?

4. What is the average speed during (*a*) the first second, (*b*) the second second, (*c*) the third second, (*d*) the fourth second ?

5. What is the excess of (*b*) above (*a*), of (*c*) above (*b*), of (*d*) above (*c*) ?

6. What is the acceleration observed ?

7. Does the force producing this acceleration change ?

8. Does the mass which is accelerated change ?

From the above experiment, if carefully performed, we learn that **a constant force** (in our experiment the weight of the body in the scale pan) **acting on a constant mass produces a uniform acceleration.**

Experiment 2.

Remove the lump of lead from the cart and replace it with a quantity of shot or sand, leaving exactly the same body in the scale pan. Repeat the experiment, and if you find the cart moves a greater distance in the first second than when the lump of lead was used, add some shot or sand to the cart; if a less distance, take some out. Keep trying until you have such a quantity of shot or sand in the cart that it moves over

the same distance in the same time as it did when you used the lump of lead.

1. What is the force producing the acceleration in this case?

2. What is the whole mass accelerated?

3. According to our definition of equal masses, what masses must be equal?

4. Since the cart, scale pan, and the body in the scale pan are exactly the same in both cases, what body must have the same mass as the lump of lead placed in the cart in the first experiment?

Experiment 3.

Carefully remove the shot or sand from the cart and place it in one pan of an equal-arm balance, placing the lump of lead in the other pan.

What is the result?

Experiment 4.

Hang them successively from the end of a strong rubber band and note the extent to which it is stretched in each case.

What is the result?

Also place them successively in a scale-pan attached to a coil-spring, supported as shown in Fig. 38. A small pointer is fastened to the lower end of the spring, and the elongation of the spring is measured by means of a graduated scale. The position of the pointer on the scale may be determined with accuracy by so placing the eye that the pointer and its image in a mirror placed alongside the scale shall be in line.

What is the result?

The apparatus shown in Fig. 38 is usually called **Jolly's balance.**

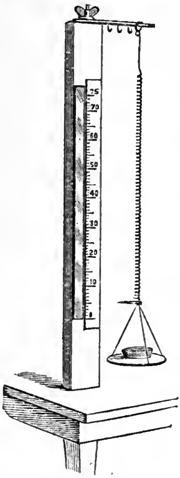


Fig. 38.

These experiments prove that **equal masses counterpoise each other at the ends of an equal-arm balance,** and that **equal masses stretch the same elastic body to the same extent,** and hence we have two other and more simple methods of finding equal masses. Thus if we find that two masses counterpoise each other at the ends of an equal-arm balance, we may infer that these masses are equal. Also, if we find that two masses stretch to the same extent, the same rubber band or the same coil spring, we may infer that these masses are equal. **We may also divide a given mass into two equal parts by so dividing it that the two parts counterpoise each other at the ends of an equal-arm balance, etc.**

II.—Description of the Balance.

The balance consists of a metal beam A B (Fig. 39), supported at the centre on the knife edge C, usually a three-cornered steel bar passing horizontally through the beam at right angles to it. The sharp lower edge of C rests on a smooth horizontal plate of steel or agate fixed on a pillar, P. Scale pans are hung by means of steel or agate plates on knife edges placed at E and F near the ends of the beam and at equal distances from its centre,

A pointer, *p*, which moves over a graduated scale, is attached to the centre of the beam, as shown in the figure. When unloaded, or when the pans are equally

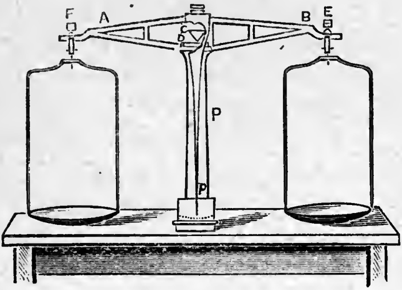


FIG. 39.

weighted, the balance should rest in equilibrium, with the beam horizontal, and the pointer at zero on the graduated scale. Every good balance should have also some device for supporting the pans.

III.—Metric Measurement of Mass.

2. Unit of Mass.

The metric unit of mass is the gramme, generally now written in English gram. It is equal to the mass of one cubic centimetre of water at 4° Centigrade.

3. Multiples and Fractions of the Unit.

A mass of	$\frac{1}{10}$ or ·1	of a **gram** (gm)	is called a	**decigram** (dgm).
"	$\frac{1}{100}$ or ·01	"	"	**centigram** (cgm).
"	$\frac{1}{1000}$ or ·001	"	"	**milligram** (mgm).
"	10	grams	"	**decagram** (Dgm).
"	100	"	"	**hectogram** (Hgm)
"	1000	"	"	**kilogram** (Kgm).

4. English Equivalents.

1 gram	=	15·4323	grains.
	=	·0022046	avoirdupois pound.
1 kilogram	=	2·2046213	avoirdupois pound.
1 grain	=	·064798950	grams.
1 ounce avoirdupois	=	28·349541	grams.
1 pound "	=	·45359265	kilograms.

5. Approximate Values.

1 gram	=	15·4	grains.
1 kilogram	=	$2\frac{1}{5}$	pounds.
1 milligram	=	·0154	grain.
1 grain	=	64·8	milligrams.
1 ounce	=	$28\frac{1}{3}$	grams.
1 pound	=	454	grams.

1. How many milligrams in 20·34 gm., 30 42 cgm., ·325 Kgm.?

2. How many kilograms in 856·3 mgm., 345·8 cgm., 934·2 gm.?

3. How many centigrams in 32·9 Kgm., 92·3 gm., 83·12 mgm.?

4. If 324 is the measure of a mass when the unit of mass is the gram, what will be its measure when the unit is (*a*) the kilogram, (*b*) the milligram?

5. Is the unit of mass a fundamental or a derived unit?

6. Weights.

For convenience and accuracy in estimating mass, sets of "weights" are used. These are pieces of metal adjusted to contain multiples and fractions of the quantity of matter contained in the selected unit.

Metric weights are usually arranged in a box in the following order (Fig. 40):

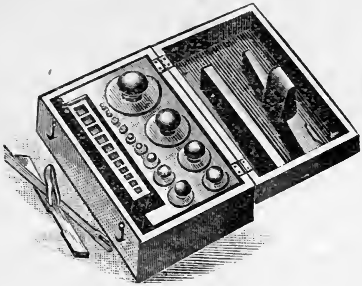


FIG. 40.

Brass Weights.			Platinum or Aluminium Weights.	
1000 gm.	50 gm.	5 gm.	5 dgm	5 cgm.
500	20	2	2	2
200	10	2	2	1
100	10	1	1	1
100				

The milligram weights are seldom used. In delicate balances where it is necessary to weigh to a milligram, a piece of platinum, generally weighing one centigram (Fig. 41), called a rider, is placed on the beam at graduated distances from the centre (Fig. 42). By this means fractions of a milligram may be estimated.

FIG. 41.

7. Rules for the Use of the Balance.

1. Keep the balance dry and free from dust.

2. See that the balance is properly adjusted, so that it will, when unloaded, either rest in equilibrium with the

pointer at the zero mark on the scale, or will swing equally on either side of zero.

3. Place the body whose mass is to be ascertained in one scale pan, and after the largest weight that can be used is placed in the other, try the others in order. Miss none.

4. To determine the equilibrium do not wait until the balance comes to rest. When it swings equally on either side, the mass in one pan equals that in the other.

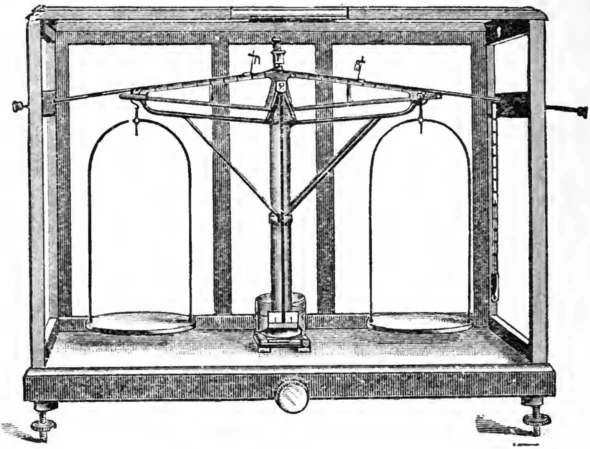


FIG. 42.

5. Place the largest weight in the centre of the pan, and the others in the order of their denominations.

6. Keep the pans supported when weights are to be added or taken off.

7. Small weights should not be handled with the fingers. Use forceps.

8. Weigh in appropriate vessels substances liable to injure the pans. For counterpoise use shot and paper.

9. Never use the balance in a current of air.

8. Experiments in Estimating Mass.

1. Measure off 50 cm. of iron stove-pipe wire, weigh it and calculate the weight in grams per centimetre in length.

2. Take another piece of the same wire, of unknown length, weigh it, and from the weight per centimetre determined in the last experiment, calculate the length of the wire. Verify your result by measuring its length with a metre scale.

What is your percentage of error?

3. Use the weights provided in your laboratory to construct from piece of brass or aluminium wire a set of centigram weights, consisting of weights of one, two, three, four and five centigrams. Bend the wires into the shape shown in Fig. 43 to indicate their denominations.

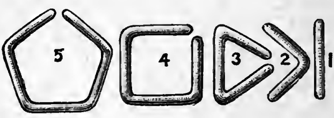


FIG. 43.

4. Cut sheet brass into strips with a pair of shears, and cut from these strips a set of decigram weights.

5. Counterpoise a beaker on a balance, run into it from a burette 100 c.cm. of water. Weigh the water.

What is the mass of the water?

What is the mass of one cubic centimetre of it?

6. Weigh one cubic centimetre of water by running it from a burette into a counterpoised watch glass.

1. How does your result compare with that obtained in Experiment 5?
2. What would one litre of the same water weigh?

7. Find the internal volume of a flask up to a certain mark by weighing the water it contains.

8. Counterpoise a beaker on a balance, and then weigh a given body by placing it in the other scale pan and determining the volume of the water, delivered from a burette into the beaker, which will counterpoise it.

9. **Density.**

The mass of a unit volume of a substance is called its density.

CHAPTER VII.

MEASUREMENT OF FORCES.

As force may be recognized in different ways, so it may be measured in different ways. But as we have considered force as tendency to acceleration, **the magnitude of a force in any particular case is most naturally inferred from the amount of acceleration resulting from the action of that force.** In our experiments for the determination of equal masses we have seen that the same force gives rise to different accelerations when acting on different masses. Hence in measuring forces both the mass acted on and the acceleration resulting must be taken into account.

1. Equal Forces.

We may define equal forces as forces which can produce **equal accelerations** upon the **same mass** or upon **equal masses.**

2. Weight—Mass.

Experiment 1.

By means of an equal-arm balance, a rubber band, or a spring balance, prepare several small equal masses. Arrange the cart as in Experiment 1, page 55. Place any convenient and fairly large mass in the cart, and place one of the equal masses in the scale pan. Carefully determine the distance the cart moves from rest in 1, 2, or 3 seconds. Replace the mass in the scale pan with another of the equal masses and

repeat the experiment, making the same observations as before.

1. How do you find the distances traversed by the cart in equal times to compare ?

2. Compare the mass moved in one case with that moved in the other case.

3. What is the total mass moved in first case ?

4. What in second case ?

5. From our definition of equal forces, what forces must be equal ?

6. How does the weight of the mass placed in the scale pan in the first experiment compare with the weight of mass placed in it in the second experiment ?

7. Hence compare the weights of equal masses at the same place on the earth's surface.

In these experiments we find that the cart, load, etc., moves over the same distance from rest in the same time (say two seconds) in one trial as in the other. The total mass moved in the one case is equal to the total mass moved in the other, viz., cart + load + pan + mass in pan. Hence, from our definition, the force acting in the one case is equal to the force acting in the other. The force acting in 1st case is weight of pan + weight of mass in pan, and the force acting in 2nd case is weight of pan + weight of mass in pan. Now the pan is the same in both cases, therefore its weight must evidently be the same in both cases. Therefore the weight of mass in pan in 1st case must equal the weight of mass in pan in 2nd case. But these masses are equal masses. Therefore **equal masses have equal weights.** This conclusion is confirmed by experiments

much more delicate though not so simple as the one above.

Since we know that in the same place equal masses have equal weights, **we can measure forces by balancing them against the weights of known masses.**

3. Mass—Acceleration.

Experiment 2.

Arrange once more the cart, scale pan, etc., as in the previous experiments. Load the cart with shot or sand and place a small quantity of the same in the scale pan. Carefully ascertain the acceleration resulting. Transfer from the scale pan to the cart, until the mass supported by the string as ascertained by the use of a balance is reduced one half, and again carefully ascertain the acceleration resulting.

1. How does the whole mass accelerated in one case compare with the whole mass accelerated in the other case?

2. How does the force producing the acceleration in one case compare with the force producing the acceleration in the other case?

3. How does the acceleration resulting in one case compare with the acceleration resulting in the other case?

4. What connection do you find between the accelerations produced by two **different** forces acting on the **same mass**?

From the above and similar experiments we learn that, **if different forces act on the same mass, or on equal masses, they produce accelerations directly proportional to the forces acting.**

Experiment 3.

By means of a balance prepare two masses, A and B, of some heavy material such as lead, making the mass of A

double that of B. Place A and B on a book, and, holding it at a few feet above the floor, very suddenly pull the book aside, thus allowing both to drop from the same height at the same instant. Carefully observe A and B as they fall.

1. Does one reach the floor first or do both reach it together?

2. How does the acceleration of A compare with that of B?

3. How does the mass of A compare with that of B?

4. How does the force acting on A during its fall compare with that acting on B?

5. How does the product of the measure of the mass of A into the measure of its acceleration compare with the product of the measure of the mass of B into the measure of its acceleration?

From the foregoing experiments we see that **if two different forces act on two masses the product of the measure of the first mass into the measure of its acceleration is to the product of the measure of the second mass into the measure of its acceleration as the force acting on the first mass is to the force acting on the second mass.**

4. Second Law of Motion.

Newton expressed this conclusion as follows:— **"Change of motion is proportional to the impressed force, and takes place in the direction of the straight line in which the force acts."**

In this statement, "change of motion" means a quantity which is measured by the product of the measure of the mass accelerated into the measure of the acceleration. It follows as a particular case of the foregoing law that no change whatever takes place in the motion of a body

which is subject to no external force. This fact may be stated by itself as follows :—

5. First Law of Motion.

"Every body continues in its state of rest or of uniform motion in a straight line, except in so far as it may be compelled by force to change that state." This is generally known as Newton's First Law of Motion.

6. Unit of Force.

The second law furnishes the most natural and scientific method of estimating the magnitude of a force, viz., by observing the "change of motion" it produces. However, for ordinary purposes it has been found convenient to estimate a force by observing the mass it will support against gravity at the surface of the earth. In this case **we take as our unit force the force that will support the unit mass,** *e.g.*, the pound or the gram. Thus a pound force means the force that will support the pound mass at the surface of the earth, etc.

7. Double Meaning of the Words, "Pound," "Gram," etc.

It will be seen that we use the word "pound" in a double sense. We use it as the name of a particular mass, and also as the name of the force required to support that mass at the surface of the earth. If there is any chance of being misunderstood, it is well to use the phrase **pound mass** or **pound force**, according to which is intended. The same may be said of the words "gram," "kilogram," etc.

Experiment 4.

Drop a mass of lead, and, by means of your pendulum, determine as accurately as you can the distance it will fall freely from rest in one second.

As the resistance offered by the air to the motion of the lead through it is exceedingly small compared with the weight of the lead, no appreciable error is introduced by neglecting this resistance and assuming that the change of motion in the lead is produced entirely by its weight.

You will find that the lead falls approximately 16 feet, or 490 centimetres, during the first second, and we have already learned from our experiments with the loaded cart that a constant force acting on a constant mass produces a uniform acceleration. Let us find the acceleration in this case.

1. What is the average velocity of the falling lead during the first second ?

2. What is its velocity at the beginning of this second ?

3. Since its acceleration is uniform, what must be its velocity at the end of the second ? (Art. 6, page 33.)

4. What is its acceleration ?

8. Acceleration Due to Gravity.

From such experiments as the above, and others more exact though less simple, we learn that **a body falling freely at the surface of the earth is accelerated approximately 32 feet per second per second, or 980 centimetres per second per second.** It is customary to use the letter g to represent this acceleration. The value of g is found to vary slightly according to the latitude, showing us, as we also learn in other ways, that the same mass has slightly different weights at different points on the earth's surface.

9. Law of Gravitation.

Sir Isaac Newton, from experiments and from observations of the motion of the moon, etc., arrived at the following conclusion:

Between any two bodies in the universe there is a mutual attraction jointly proportional to the masses of the bodies, and inversely proportional to the square on the distance between their centres of mass. For example, if the mutual attraction between two one-pound masses at a distance of one foot is taken as the unit, the attraction between a three-pound mass and a two-pound mass at a distance of one foot is (2×3) units, and the attraction between a four-pound mass and a five-pound mass at a distance of three feet is $\frac{4 \times 5}{3^2}$ units $= \frac{20}{9}$ units.

10. Experiment of Cavendish.

At the close of the last century Cavendish determined by experiment the attraction between unit masses at the unit distance. His experiment was arranged mainly as follows:

He prepared a light rod about 2 metres long, with balls of lead mm^1 about 5 centimetres in diameter at the ends, which he suspended from the centre by a fine wire. Near the small balls he placed large balls of lead MM^1 about 30 centimetres in diameter, as shown in Fig. 44. The rod was deflected until the torsion in the suspending wire was just balanced by the attraction. After noting the deflection the large masses were placed on the

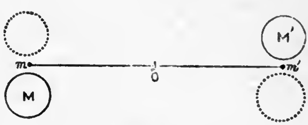


FIG. 44.

other side of the small ones, in the positions indicated by the dotted circles, and the deflection was again noted. The mean of the two deflections was taken. By observing the period of vibration of the suspended rod under the torsion of the suspending wire, this torsion was determined, and hence he found the mutual attraction between the masses. The masses being known, and their distance apart being also known, he was able, by making use of the law of gravitation, to calculate the attraction between two unit masses at the unit distance from each other.

11. Mass of the Earth.

By comparing the attraction between unit masses at the unit distance with the weight of the unit mass at the earth's surface and again applying the law of gravitation, Cavendish estimated the mass of the earth to be 5·48 times as great as that of an equal volume of water. This experiment in modified forms has been repeated by others with approximately the same results.

12. Third Law of Motion.

It has already been observed that every force is only one aspect of a stress, or in other words, that two masses are always associated with any force. Careful examination shows that the "**change of motion**" resulting in the one mass is exactly equal and opposite to that resulting in the other.

Newton expressed this fact by saying: "**To every action there is always an equal and contrary reaction; or action and reaction are equal and opposite.**"

QUESTIONS.

1. Is a kilogram weight resting on a table a force ?

2. Explain clearly what is meant by a force of a pounds, b grams.

3. A force acts on a mass of 10 grams. Compare the acceleration with that produced by the same force acting on (a) 20 grams mass, (b) 5 grams mass.

4. A force acts on a mass of 10 grams and produces an acceleration of 10 cm. per sec. per sec. Another force acts on a mass of 5 grams and produces the same acceleration. Compare the forces.

5. A force is capable of producing in a certain mass an acceleration of 10 cm. per sec. per sec., and in another mass an acceleration of 20 cm. per sec. per sec. Compare the masses.

6. Why is a rider frequently unhorsed when the horse suddenly turns in a new direction ?

7. Why is the outside bank worn away when a river takes a sharp turn ?

8. Why does a player in catching a cricket ball allow his hand, the instant the ball touches it, to be carried backward in the direction in which the ball is moving ?

9. A ship in firing a broadside inclines to the opposite side. Why ?

10. What effect would firing (a) the bow guns, (b) the stern guns have on the speed of a vessel ? Explain the reason.

11. Why does a sky-rocket ascend ?

12. Explain the following facts derived from experience : (a) It is an advantage to run before a leap. (b) It is safest to skate quickly over thin ice.

13. If a mass of 10 grams were raised 50 cm. above the surface of the earth, what would happen if exactly at that instant gravity

ceased to act? What would happen if gravity ceased to act after the body had fallen through 25 cm.?

14. If the mass of the earth is 80 times, and its diameter is four times that of the moon, how does the weight of any mass at the surface of the earth compare with the weight of the same mass at the surface of the moon?

15. What is the weight of a pound mass at the centre of the earth?

16. At what distance from the earth's surface is the weight of any mass one fourth of its weight at the surface?

CHAPTER VIII.

MEASUREMENT OF ENERGY AND WORK.

1. Energy—Mass.

We have already seen (page 38) that a body possesses energy by virtue of its mass and its velocity. Let us examine the connection between the **amount of energy** a body possesses and its **mass.**

Let A and B be two bodies, the first having a mass of one pound and the second a mass of two pounds. Let both have the same velocity.

Imagine B to be divided into two equal parts.

1. How does the energy of each part of B compare with the energy of A ?

2. How does the energy of the whole of B compare with that of one part of B ?

3. How does the energy of B compare with that of A ?

The energy of a body is directly proportional to its mass.

2. Energy—Space.

Consider a clock's weight. As the weight falls work is done on the weight by the energy which causes gravitation, which energy instead of being stored up in the weight is expended as fast as it is acquired (since the weight is not accelerated) in moving the works of the clock, that is, in overcoming the friction among the wheels, etc.

1. How does the work done in this case during one hour compare with the work done during another hour?

2. How does the distance the weight descends during one hour compare with the distance it descends during another hour?

3. How does the work which the energy causing gravitation does on the weight, while this weight is falling two inches, compare with the work done while it is falling one inch?

4. Compare the work done on a one pound mass falling one foot with the work done on a two pound mass falling the same distance.

From the above it is evident that **the work which the energy causing gravitation does on a falling body near the earth's surface is directly proportional to the distance the body falls.** The force brought into action in this case is the weight of the body, and therefore a constant force. Hence we may say that **the work done in any case is directly proportional to the force brought into action, and also directly proportional to the distance through which motion takes place in the direction of the force.**

3. Definition of Force.

The above fact may be stated thus: the force arising in any transference of energy is directly proportional to the amount of energy transferred and inversely proportional to the distance through which motion takes place during the transference. That is

$$\text{Force} = \frac{\text{Energy}}{\text{Space.}}$$

We can now clearly see the analogy already indicated (page 48) between force and velocity.

$$\text{Velocity} = \frac{\text{Change of position}}{\text{Time.}}$$

From this we define velocity as the **time-rate of change of position.**

Hence from the statement

$$\text{Force} = \frac{\text{Energy}}{\text{Space.}}$$

We may define force as the **space-rate of transference of energy.**

4. Unit of Energy.

From the foregoing it will be seen that a convenient unit of energy is the energy transferred when a unit force is brought into action and motion results through a unit distance. Thus, if a pound weight falls vertically one foot, we say that one unit of energy has been transferred. The same amount of energy is transferred, of course, if a pound force acting in any direction causes its point of application to move one foot in the direction of this force. This unit is called a **foot-pound.** We shall have, of course, a unit of energy corresponding with every combination of unit force and unit distance, for example, the **gram-centimetre,** the **kilogram-metre,** etc.

5. Unit of Work.

As doing work is simply transferring energy, we take as our unit of work the work done in transferring a unit of energy. The unit of work is called by the same name as the unit of energy.

6. Energy—Velocity.

Let us consider a body falling freely near the surface of the earth. In this case the energy causing

gravitation does work on the falling body, which, as the body falls freely, is stored up as energy in this body. We have seen that a body falls freely 16 feet in one second, and has at the end of the second a velocity of 32 feet per second. Now, if a pound mass falls 16 feet, the energy which causes gravitation does 16 foot-pounds of work upon it, and as this energy is retained by the body, the pound mass must have 16 foot-pounds of energy. But the body in this case has a velocity of 32 feet per second, therefore a pound mass having a velocity of 32 feet per second must have 16 foot-pounds of energy. If the pound mass is allowed to fall freely during two seconds it is found to fall 64 feet, and to have at the end of the two seconds a velocity of 64 feet per second. Hence a pound mass with a velocity of 64 feet per second has 64 foot-pounds of energy. Thus we see that doubling the velocity of a mass increases its energy fourfold. In short we find that **the energy of a body is directly proportional to the square of its velocity.**

1. What is the energy of a pound mass having a velocity of 96 feet per second ?

2. Find the energy of a five pound mass with a velocity of 64 feet per second.

3. How much is the energy of a body increased by changing its velocity from 10 cm. per second to 30 cm. per second ?

7. Rate of Working.

A man does 72,000 foot-pounds of work in one hour.

1. How much work does he do in one second ?
2. How much in one minute ?
3. Describe his time-rate of working.

8. Power.

Time-rate of working is called **power.** The most scientific unit of power is one unit of work in one unit of time, but for practical purposes a much larger unit called **one horse-power** is used. One horse-power is 33,000 foot-pounds per minute, and is about the rate at which a good horse is capable of working during the ordinary working day.

QUESTIONS.

1. What is the measure of 100 foot-pounds of energy when 2 pounds is the unit of force and 1 yard is the unit of distance?

2. A man pumps 1,000 gallons of water per hour from a well 20 feet deep; at what rate does he work? (One gal. of water weighs 10 lbs.)

3. How long would it take a 10 horse-power engine to raise 1,000,000 gallons of water to a height of 330 feet?

4. A bullet weighing 1 gm. is fired from a rifle weighing 1 Kgm. Compare (*a*) the momentum (mass × velocity), (*b*) the velocity, (*c*) the momentum, of bullet with that of the rifle.

5. 6,600 cubic feet of water flow per hour over a dam 48 feet high. If a cubic foot of water weighs 1,000 ounces, what is the power of this fall?

6. How much potential energy has a mass of 90 Kgm. 500 m. above the surface of the earth?

CHAPTER IX.

TRANSMUTATION OF MATTER.

I.—Chemical Change.

Experiment 1.

Place in a clean, dry test-tube a teaspoonful of granulated sugar. Hold the tube in the flame of a spirit lamp or Bunsen burner (Fig. 45). Hold some cold polished metal body above the mouth of the tube.

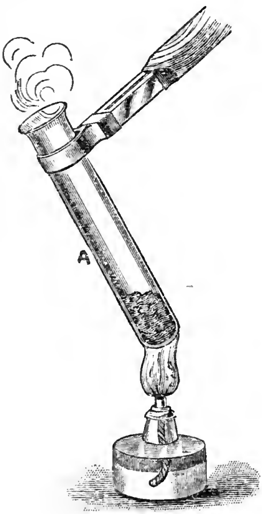


FIG. 45.

1. What changes take place in the appearance of the substance in the tube?

2. What is given off from the mouth of the tube?

3. What is observed on its sides?

4. What is the colour of the substance left in it?

5. What is its taste?

6. Is it soluble in water?

7. Is it sugar? Give reasons for your answer.

Experiment 2.

By means of a pair of pliers hold a piece of magnesium

ribbon in the flame of a burner (Fig. 46) until it takes fire; remove it, and hold it over a piece of dark paper until combustion ceases.

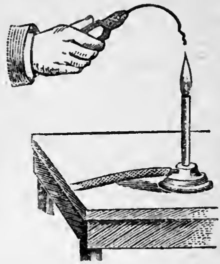


Fig. 46.

1. What kind of fumes were given off?

2. How does the substance remaining on the paper differ from the magnesium before combustion?

3. Is it magnesium?

Experiment 3.

Place a small piece of copper in a test-tube and add about twice its weight of nitric acid. Keep the mouth of the tube away from your face, and do not inhale the vapours.

1. What is the colour of the vapours given off?

2. What is the colour of the liquid in the tube?

Place a few drops of the liquid on a sheet of mica held over the flame of a burner.

1. What is the colour of the substance remaining after the liquid is evaporated?

2. Is it soluble in water?

3. Is it copper?

The substances used in the last three experiments are evidently different in identity from those formed from them. They are said to be transmuted or changed chemically into the others.

Transmutation of matter, or chemical change, is a change in which an alteration of substance has occurred.

All matter is subject to transmutation, and changes of this kind are constantly going on around us.

Give several examples of transmutation of matter.

1. **Chemistry.**

Chemistry is that branch of Science which deals with the changes which affect the composition of substances.

II.—Elements and Compounds.

Experiment 1.

Pulverize in a clean mortar some crystals of silver nitrate. Take a test-tube about 15 centimetres long and 12 millimetres in diameter, counterpoise it on a balance, and place in it one gram of the powdered nitrate. Heat the bottom of the tube gently in the flame of a spirit lamp or Bunsen burner. When the salt has melted heat more strongly until all action ceases. Weigh the residue.

1. What changes take place in the appearance of the substance in the tube ?
2. What is given off from the mouth of the tube ?
3. What is the weight of the residue ?
4. Is your answer to this question the same as that of the other students in the class who have performed this experiment ?
5. If so, what do you believe to be the percentage of residue always remaining when silver nitrate is heated ?

In this experiment a substance (silver) differing in property from the silver nitrate, and weighing less than it, was formed from it; but thè chemist has discovered no means of changing a piece of silver into any lighter body. By continuing chemical changes similar to this, which result in lighter forms of matter, chemists are lead to a lim-

ited number of forms each of which cannot be made to give any lighter form of matter. From these, in most cases, the original matter may be constructed. They are, therefore, called **elements**, and those substances from which they may be derived, and which are formed from them by transmutation, are called **compounds**.

2. Element.

An element is a substance out of which alone nothing different has been obtained, or which has not been decomposed into two or more distinct and different substances.

3. Compound.

A compound is a body formed by the combination of two or more elements into one substance essentially different from its constituents, and out of which its constituent elements may be obtained.

4. Common Elements.

The elements are divided into the so-called metals and non-metals. The following is a list of the more common ones :—

Non-Metals.		Metals.	
Oxygen, Hydrogen, Nitrogen, Chlorine.	Gases.	Iron, Lead, Tin, Zinc,	
Bromine,	Liquid.	Copper,	
Iodine, Carbon, Sulphur, Phosphorus, Arsenic, Silicon.	Solids.	Silver, Gold, Nickel, Aluminium, Sodium, Potassium,	Solids.
		Mercury,	Liquid.

III.—Indestructibility of Matter.

Experiment 1.

Take two small light beakers, fill each about one-third full of distilled water, add a few crystals of silver nitrate to the one and a little common salt to the other. When the solids have dissolved, weigh the two. Pour the contents of one beaker into the other and again weigh both beakers.

1. What change takes place in the appearance of the contents?
2. Is the substance at the bottom of the beaker soluble in water?
3. Is it either common salt or silver nitrate? How do you know?
4. Has transmutation taken place?
5. Is there any loss or gain in matter?

This experiment is illustrative of a general law. The careful application of weight to innumerable transmutations of matter has lead to the belief that in all the various changes in the composition of substances the total amount of matter remains constant. Whenever matter apparently disappears, for example, in ordinary combustion, it continues to exist in some other form. The law may be thus stated:

5. Law of Conservation of Matter.

In all transmutations of matter, no matter is created or destroyed; in short, the total amount of matter in the universe is a constant quantity.

CHAPTER X.

PROPERTIES AND LAWS OF SOLIDS.

I.—Hardness.

The resistance which a body offers to being abraded by another.

It is a relative property. A body which is hard when compared with one body may be soft when compared with another. The relative hardness of two bodies is ascertained by trying which will scratch the other.

Experiment 1.

Test the relative hardness of the following substances, and make a list of them arranged in the order of hardness: glass, slate, lead, copper, wrought iron, steel.

Experiment 2.

Take two pieces of steel piano wire, make each red hot, allow one to cool slowly, but cool the other quickly by dipping it into cold water. Scratch each with a file.

Which is the harder?

Experiment 3.

Repeat Experiment 2, using copper instead of iron wire.

Which is the harder, the wire cooled quickly or that cooled slowly?

1. Tempering—Annealing.

Changing the hardness of a metal by heating it and cooling it in different ways is called **tempering.**

The process of making a hard and brittle metal softer and more flexible is called **annealing.**

How is iron annealed ? How is copper ?

2. Hardness and Density.

1. Which is the denser metal, iron or gold ? Which is the harder ?

2. Which is the denser metal, lead or platinum ? Which is the harder ?

3. Is there any relation between hardness and density ?

II.—Ductility.

The property of being extended in length by being drawn out into wires or threads.

Experiment 1.

Take a piece of glass tubing or a glass rod, heat it in the flame of a Bunsen burner or spirit lamp until it becomes quite soft, then draw it out (Fig. 47).

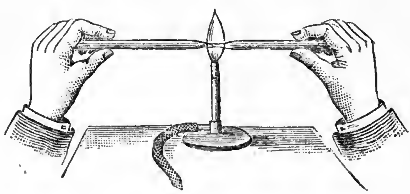


FIG. 47.

Experiment 2.

Compare the ductility of a piece of sealing wax at the ordinary temperature with that of a piece which has been heated for a short time in boiling water.

Many metals are quite ductile even when cold. The following is a list of the more common ones :—Gold, silver, platinum, iron, copper, aluminium, zinc, tin, lead.

Is there any relation between (*a*) density and ductility, (*b*) hardness and ductility ?

Wires are made by drawing the metal through holes in hard metal plates.

III.—Malleability.

The property of being extended in surface when hammered or rolled.

Gold is the most malleable of metals. It can be beaten out into sheets so thin as to be quite transparent, having a thickness of not more than $\frac{1}{120000}$ cm.

1. How are the relative positions of the molecules of a body affected by its being extended in (*a*) surface, (*b*) length ?

2. Why is it that most ductile metals are malleable ?

IV.—Plasticity.

The property of changing shape under the action of a continuous force without exhibiting a tendency to regain the original form.

Experiment 1

Support one end of a stick of sealing wax (Fig. 48) and

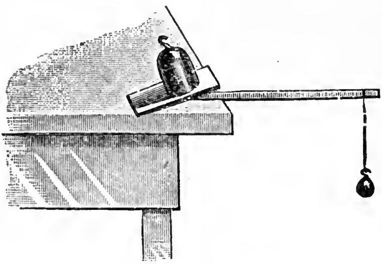


FIG. 48.

hang a weight of about 50 grams from the other end. Allow it to stand for two or three days.

1. What change has taken place in the shape of the sealing wax ?

Remove the weight.

2. Does the wax recover its original shape ?
3. Name some plastic bodies.
4. Is ice plastic ? Is glass ?

V.—Tenacity.

The resistance which a body offers to the separation of its parts.

Experiment 1.

Determine the strength of different wires by fastening one end of each to a peg and the other to a spring balance, and grad-

ually pulling on the balance until the wire breaks (Fig. 49).

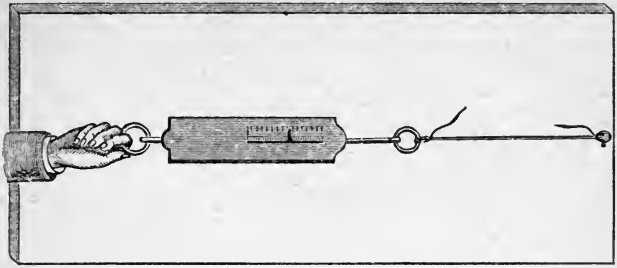


FIG. 49.

1. What other properties of bodies are dependent upon tenacity?

2. Wire ropes are usually stronger than bars of the same metal of equal mass and length. How does drawing a metal into a wire affect its tenacity?

VI.—Elasticity.

Experiment 1.

Try to stretch a piece of rubber band or tubing. Press a rubber eraser against a hard substance. Try to bend it. Squeeze in the hand a hollow rubber ball containing air.

1. What changes take place in the volume or the shape of the band, of the eraser, and of the ball, when force is applied to each?

2. What happens when the force is reduced or ceases to act?

3. Elasticity.

The property of a body in virtue of which, after its size or shape has been altered by the action of force, it reacts against the force and returns to its original size or shape, more or less completely, on the removal of the force, is called elasticity. That is, the elasticity is the internal stress which is called out in a body when it is subject to a strain.

When the strain is one of change of volume (compression or dilatation) the stress produced is called **elasticity of volume**; when the strain is one of change of shape (distortion) the stress which is called out by it is called **elasticity of form.**

1. Which of the bodies used in Experiment 1 possess elasticity of volume? Which elasticity of form?

2. What elasticities are possessed by solids? by liquids? by gases?

4. Limit of Elasticity.

Experiment 2.

Arrange apparatus as in Figure 50. Fasten one end of a piece of copper wire about No. 26 or 30, and about 50 cm. long to the support. To the other end attach a scale pan. Tie a thread around the wire at A and another at B. Place a small weight on the scale pan, and by means of the graduated scale placed on a piece of mirror glass, observe the elongation of A B. Remove the weight. Repeat the experiment several times, removing the weight each time and replacing it with a heavier one.

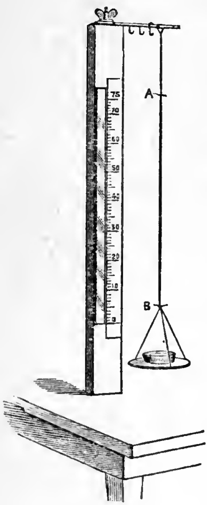


FIG. 50.

1. Did the points A and B return each time to their original positions?

2. If not, after the addition of what weight did they cease to do so?

3. What change must have taken place in the arrangement of the molecules in the wire when the weights were placed in the pan?

Experiment 3.

Fasten one end of a piece of copper wire A in a clamp or vise, as shown in Fig. 51. Place a pointer B opposite the other end.

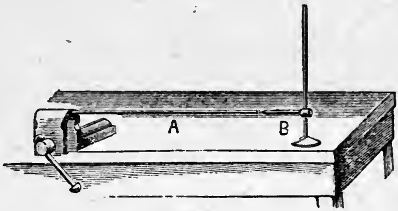


Fig. 51.

Bend the wire a little by pulling the free end aside a **short** distance. Let go.

Does the wire take its original position when it ceases vibrating?

Repeat the experiment, bending the wire a little more each time.

Is there a limit beyond which if it is bent, it will not take its original position when the disturbing force is removed?

The property of a body in virtue of which it may be bent is called flexibility.

1. How does elasticity differ from flexibility? Give illustrations.

2. What change takes place in the arrangement of the molecules on (*a*) the convex, (*b*) the concave side of a body, when it is bent?

Experiment 4.

Fasten one end of a copper wire, about No. 10 and 50 cm. long, to a support, and to the other end attach a heavy weight to which is fastened a pointer (Fig. 52). Note the position of the pointer on a circular scale drawn on paper. Twist the weight around a **little way.**

Does it return, after it ceases vibrating, to its original position?

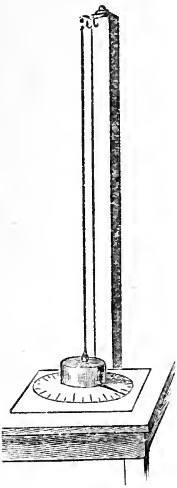


Fig. 52.

Repeat the experiment, turning the weight more each time.

Is there a limit beyond which, if the weight is turned, the pointer does not return to its original position.

A body is said to be perfectly elastic when it recovers completely its volume or shape after strain. Many solids are perfectly elastic if not strained beyond a certain limit called the **limit of elasticity.** When strained beyond this they do not completely recover their original volume or shape, but take a permanent "set."

1. If a heavy load strains a bridge beyond its limit of elasticity, what effect is produced on the shape of the bridge? What effect would the same load produce if it passed over again?

2. Why do the springs of carriages often become "sagged"?

3. Name some bodies (*a*) in which the limit of elasticity is soon reached, (*b*) in which the limit of elasticity is near the breaking point, (*c*) which have a high limit of elasticity?

4. Are there any bodies belonging to (*a*) and (*b*)? to (*a*) and (*c*)? to (*b*) and (*c*)? If so, give examples.

5. Has the length of time during which a force acts any effect on the limit of elasticity of a body?

Experiment 5.

To answer this question, take a wooden bar A, support

it as shown in Fig. 53, and place on it a weight which does not apparently strain it beyond its limit of elasticity. Allow the weight to remain on the bar for a few days.

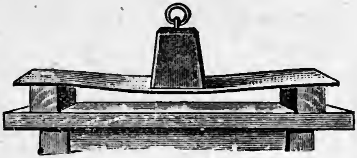


FIG. 53.

1. Is the bar permanently bent?

2. Why do archers keep their bows unbent when not in use?

3. Have gases a limit of elasticity? have liquids?

6. Measure of Elasticity.

The elasticity of a body is measured, not by the amount of change in shape or in volume which it will undergo and still regain its original shape or volume, but by the force with which the displaced particles will tend to revert to their original positions. This is the force necessary to produce the change in shape or volume. For example, liquids are more elastic than gases, because greater force is necessary to produce a specific change in the volume of a liquid than in the volume of a gas, since the particles of the liquid tend with greater force to return to their original positions.

Generally, the elasticity of solids is greater than that of liquids.

1. To which must the greater force be applied to change its length by one millimetre, a bar of rubber or one of steel of the same size and length?

2. Which is the more elastic ?

3. Which is the more extensible ?

4. Which is the more compressible ?

5. Why does a ball rebound when it strikes a hard surface ?

To answer this question, cover the surface with ink or paint. Touch lightly the ball to the surface and note the size of the spots made on the ball and on the surface. Now let the ball drop from a height on the surface and again observe the size of the spots.

1. How do the spots made in the two cases compare ?

2. What change must have taken place in the ball when it came in contact with the surface ?

3. What would this cause ?

VII.—Structure—Crystalline and Amorphous.

Experiment 1.

Dissolve 100 grams of alum in 500 cubic centimetres of water. Hang several strings in the solution and set aside for a few hours.

1. Are the pieces of alum which have separated from the solution alike in shape ?

2. Study their forms and make drawings of some of them.

Experiment 2.

Repeat Experiment 1, using (*a*) a solution of copper sulphate, (*b*) a mixture of the solution of alum and the solution of copper sulphate.

Experiment 3.

Clean a strip of glass, slightly warm it, and pour upon it a few drops of a hot solution of ammonium chloride.

1. Describe what takes place.

2. What is the substance left on the glass ?

Experiment 4.

If you have a porte lumiere or projection lantern, wet a clean glass plate the size of a lantern slide with the hot solution of ammonium chloride, place it in the slide holder and focus it on the screen.

Observe the beautiful arborescence.

Experiment 5.

Pour a saturated solution of common salt into a saucer. Put it away and keep it free from dust for a few days.

What do you observe on the bottom of the saucer ?

Experiment 6.

Obtain pieces of mica, chalk, coal, copper sulphate, glass, Iceland spar, roll sulphur, and wood. Try to cut or split them in different directions.

1. Is each cut or split in every direction with equal ease ?

2. Are the surfaces exposed at all separations of the same substance the same in appearance ? If not, point out some of the differences.

7. Crystalline—Amorphous.

When the particles of which a body is composed are arranged in a more or less regular form the body is said

to be **crystalline** in its structure; but when these particles possess no apparent regularity in their arrangement it is said to be **amorphous**

1. Which of the bodies named in Experiment 6 above are crystalline and which amorphous?

2. Is ice crystalline? Observe it when it **begins** to form. Place a thin sheet of it before the condenser of a porte lumiere or projection lantern and focus on the screen.

3. Is snow crystalline? Place a few flakes on a dark cloth and observe them through a magnifying glass.

The variety of forms in which the particles of different substances arrange themselves is almost endless. This is the case probably because the attraction of cohesion is not the same all round the molecule, but like the attraction of a magnet, is concentrated at certain points or poles. When the molecules are free to move, these points, on account of their mutual attractions or repulsions, take set positions, and the structure of the body thus becomes regular in form.

This tendency to arrange themselves in regular order is perhaps possessed by the molecules of most bodies; and even when, on account of the lack of freedom of the molecules, it does not render itself apparent, it is no doubt often still present. For example, wrought iron is amorphous, but by constant jarring it becomes crystalline. Here the molecules receive a certain amount of freedom at each jar, and in course of time the constant tendency to regularity of structure becomes apparent.

QUESTIONS.

Give the properties of the following solids which make them useful for the purposes indicated :

1. Lead for (*a*) water pipes, (*b*) bullets.
2. Rubber for (*a*) bicycle tires, (*b*) overshoes.
3. Iron for (*a*) boiler plates, (*b*) chains.
4. Steel for (*a*) pens, (*b*) watch springs, (*c*) swords.
5. Silk for (*a*) clothes, (*b*) thread.
6. Hair for (*a*) mattrasses, (*b*) mixing in mortar.
7. Cork for (*a*) bottle stoppers, (*b*) soles for shoes.
8. Leather for (*a*) harness, (*b*) shoes.

CHAPTER XI.

PROPERTIES AND LAWS OF LIQUIDS.

I.—Fluidity—Viscosity.

Experiment 1.

Pour several liquids such as alcohol, water, oil, syrup, honey, tar.

1. Do they all flow with equal freedom ?
2. Is the shape of each changed by the action of the smallest possible force ?

A **perfect fluid** would possess no rigidity of form whatever, but in actual liquids there is always a certain amount of rigidity due to internal friction among their molecules.

1. Viscosity.

The resistance to flow due to internal friction of the molecules of a liquid is called viscosity.

Liquids differ widely in fluidity. Some, like ether, are quite mobile; while others, like pitch, are very viscous.

The rigidity of a perfect solid would be infinitely great, and the viscosity of perfect fluid infinitely small.

2. Surface Viscosity.

Experiment 2.

Place a clean, dry sewing needle on the surface of water by lowering it so that both ends will touch the surface at

once. To do this use a fine wire bent in the form shown in Fig. 54. Keep trying until you succeed in leaving the needle floating on the surface of the water.

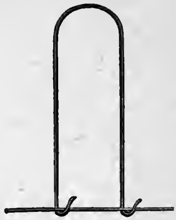


FIG. 54.

What is the form of the water surface around the needle?

Break the surface of the water near the needle by thrusting a finger into the water.

What takes place?

Experiment 3.

Magnetize a sewing needle by rubbing it with a permanent magnet (Experiment 6, page 50), and place it on the surface of water as in the last experiment.

In what direction does the needle set itself?

Place another magnetized needle on the surface of a soap solution.

What position does this needle take on the surface?

Suspend by a fibre the magnetized needle beneath the surface of the soap solution.

What position does the needle now assume?

The superficial film of a liquid is more viscous than the interior. This film therefore is hard to break, and bodies which would naturally sink if placed in the interior of the liquid are borne up by it.

II.—Cohesion—Adhesion.

Experiment 1.

Place a piece of wood in water, take it out and observe its surface.

1. What do you find on the surface of the wood?
2. What force holds it together?
3. What force holds it to the wood?

Experiment 2.

Repeat Experiment 1, using mercury instead of water.

How do you account for the difference in the result?

Experiment 3.

Fasten to the centre of a glass disc with sealing wax a wire staple of the form shown in Fig. 55, and tie to this a **thin** rubber band, and gently lower the disc until its surface touches the surface of the water. Lift up on the rubber. Examine the lower surface of the disc when it has separated from the water.

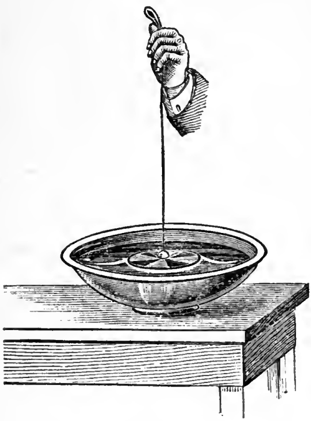


Fig. 55.

1. What evidence had you that you had to exert force to separate the disc from the water?

2. In separating the disc from the water, what force was overcome, the cohesion among the articles of the disc, the adhesion between the disc and the water, or the cohesion among the particles of the water? Give your reasons.

Experiment 4.

Repeat Experiment 3 after having greased the lower surface of the disc.

Was force necessary to separate the disc from the water? If so, what force had to be overcome to cause the separation?

Experiment 5.

Repeat Experiment 3, using mercury instead of water.

1. Is there any adhesion between the disc and the mercury?

2. Is there any cohesion among the particles of the mercury?

3. In pouring liquids from vessels a glass rod is often placed as shown in Fig. 56. Why does this prevent the liquid from running

FIG. 56.

down the side of the vessel? Would it be of any use in pouring mercury from a glass vessel? Give reasons for your answers.

III.—Capillarity.

Experiment 1.

Dip a clean glass plate (*a*) in water; (*b*) in mercury.

1. Make drawings of vertical sections of the surfaces of the water and the mercury around the plate.

2. Does the water wet the plate? Does the mercury?

3. The adhesion between the water and the glass is greater than the cohesion in the water, and the cohesion in mercury is greater

than the adhesion between the mercury and the glass. How does this explain the difference in the position of the liquid surfaces around the plate ?

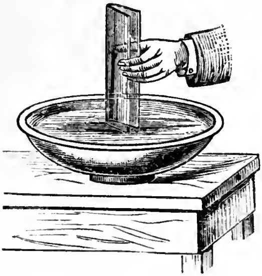


FIG. 57.

Experiment 2.

Hold two glass plates with the edges together at one side, but kept a little apart at the other (Fig. 57). Place the plates vertically in (*a*) water, (*b*) mercury.

Make drawings showing the position of the surfaces of the water and of the mercury on the outside of the plates and between them.

Experiment 3.

Dip vertically into (*a*) water, (*b*) mercury, a glass tube the bore of which is about one millimetre in diameter

1. Does the water or the mercury rise in the tube ? Is either depressed ?

2. What is the form of the surface of (*a*) the water, (*b*) the mercury in the tube ?

Repeat the experiment, using tubes of smaller bore.

In which is there the greatest difference in level between the surface of the liquid in the vessel and its surface in the tube ?

Experiment 4.

Take two capillary tubes of the same bore, place one in alcohol and the other in water.

Does the water rise to the same height in the one tube as the alcohol does in the other ?

Experiment 5.

Take two capillary tubes of the same bore, dip one into any liquid and the other into the same liquid at a higher temperature.

In which is the difference of level between the liquid within the tube and that without, the greater?

Phenomena of the kind illustrated in the foregoing experiments are known as **capillary phenomena**, because they take place in tubes with capillary or hair-like openings.

3. Laws of Capillarity.

1. **Liquids rise in tubes when they wet them, and are depressed when they do not.**

2. **The ascension or depression is inversely as the diameter of the bore of the tube for the same liquid, but differs with different liquids.**

3. **The ascension and depression increases when the temperature of the liquid decreases.**

Experiment 6.

Take tubes of the form shown in Figure 58; pour water into one and mercury into the other.

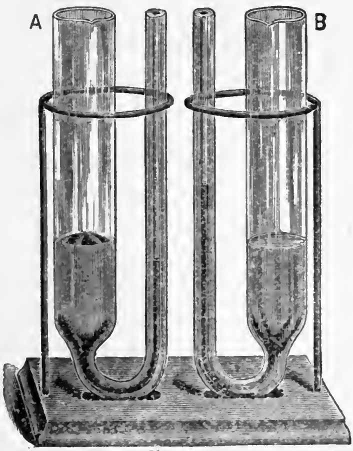


FIG. 58.

Account for the forms of the surfaces and the differences in level observed.

Experiment 7.

Place (*a*) one corner of a lump of sugar in water; (*b*) the corner of a sheet of blotting paper in ink; (*c*) the end of a piece of loosely-woven cloth, such as a lamp wick, in water.

What takes place in each case?

Porous bodies, such as blotting paper, wood, cloth, etc., absorb liquids by capillary action, the liquid rising in the irregular spaces within the bodies.

4. Will a liquid overflow a tube by capillary action?

Experiment 8.

To answer this question, take a tube of very fine bore, place one end of it in water and hold it in a vertical position until the water rises to a considerable height in it, then depress it until the upper end comes near the surface of the water.

What change takes place in the height of the liquid within the tube as it is depressed?

IV.—Surface Tension.

Experiment 1.

Let water fall in drops from the end of a glass rod. Let some of the drops rest on a greased surface. Place a few drops of mercury on a table.

1. What is the shape of the drops of water when falling through the air? What when on the greased surface?

2. What is the shape of the drops of mercury?

3. How is small shot made?

Experiment 2.

Soften the end of a stick of sealing wax or of a glass rod by heating it.

What shape does it take ?

Experiment 3.

Make a mixture of alcohol and water of the same density as olive oil. This is most quickly done by the use of a hydrometer. With a pipette introduce some of the oil into the centre of the mixture (Fig. 59).

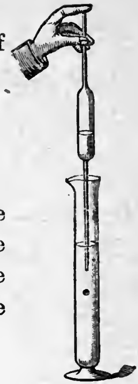


FIG. 59.

What shape does it assume ?

Experiment 4.

Make a soap solution, and with a thistle-tube blow a bubble. When the bubble has become fairly large, remove the end of the tube from the mouth and place it near the flame of a lighted candle (Fig. 60).

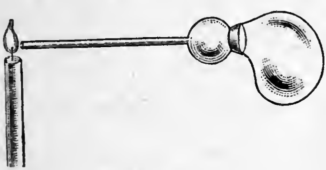


FIG. 60.

What takes place ?

Experiment 5.

Dip the mouth of a glass funnel into the soap solution, and, keeping a finger over the narrow end, lift the funnel out of the solution and observe the film on the mouth of the funnel.

Remove the finger from the narrow end.

What change takes place in the film ?

A liquid surface always tends to assume a minimum area, and therefore acts like an elastic membrane

equally stretched in every direction by a constant tension. This phenomenon is known as the **surface tension** of the liquid.

V.—Transmission of Pressure by Fluids.

Experiment 1.

Have made by a tinsmith a vessel of the form shown in Fig. 61. The short tubes inserted in the sides should be about one inch long, and from two to three inches in diameter. Tie, or fasten by hoops, pieces of thin sheet rubber over the mouth of each of the tubes. Fill the vessel with water by pouring it in through the tube A. Cork the tube A and apply pressure to any one of the diaphragms.

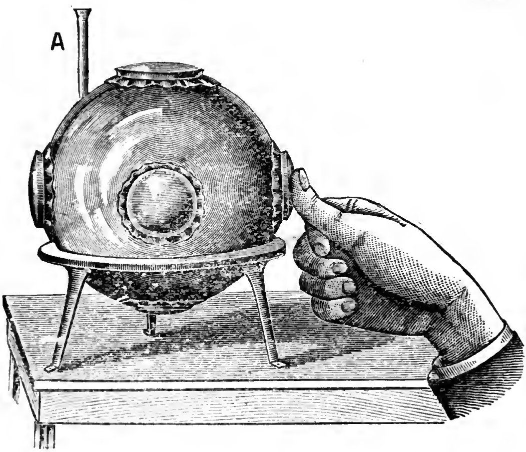


FIG. 61.

1. What effect is produced on each of the other diaphragms?

2. How then is the force which is applied to the diaphragm transmitted by the water?

Experiment 2.

Repeat Experiment 1, filling the vessel with compressed air instead of water. This can be done by attaching the tube to the foot bellows used with a blow-pipe or by using a bicycle pump.

How do the resulting phenomena compare with those observed when water was used ?

5. Law of Transmission of Pressure—Pascal's Principle.

Pressure exerted anywhere upon a mass of fluid is transmitted undiminished in all directions, and acts with equal intensity upon all equal surfaces, and in directions at right angles to these surfaces.

This is generally known as **Pascal's principle.**

Experiment 3.

Pour a small quantity of mercury into a tube of the form shown in Fig. 62. Now pour some water into the larger branch.

1. What changes take place in the levels of the mercury in the two branches ? Why ?

2. How much water do you suppose must be put into the smaller branch to bring the mercury to the same level in each branch ? Give reasons for your answer. Verify by pouring water into the smaller branch.

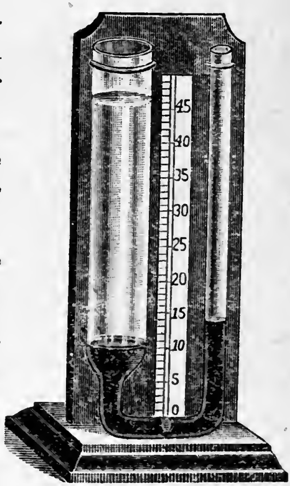


Fig. 62.

3. How does the weight of the water in the larger branch compare with that in the smaller one when the mercury is restored to the same level in each tube ?

VI.—Pressure due to Weight.

Experiment 1.

Cut the funnel shaped end from a thistle-tube, leaving about an inch of the stem connected with it. Over this slip a piece of rubber tubing about 30 or 40 cm. long, and tie a piece of thin sheet rubber over the mouth of the funnel. Make a U shaped tube by bending a piece of glass tubing into the form shown in Fig. 63. Place this in a vertical position in a holder, partially fill it with water and connect it with the free end of the rubber tubing. Press the rubber membrane with a finger.

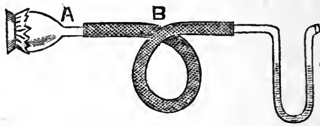


Fig. 63.

1. What change takes place in the position of the water in the tube? Why?

2. How is (*a*) an increase, (*b*) a decrease in the pressure on the membrane indicated by the water in the tube?

Fill a large jar with water **which is at the temperature of the air in the room.** Place the thistle-tube in the water and gradually lower it (Fig. 64).

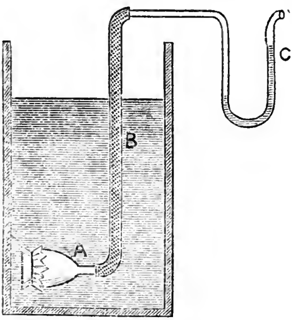


Fig. 64.

1. What change takes place in the water in the U shaped tube?

2. What change in pressure does this indicate?

When the membrane has reached the bottom of the jar, gradually lift it up.

1. What change in pressure takes place as the funnel is raised in the water? How do you know?

2. What was in contact with the membrane?

3. What then must have caused the pressure?

4. How does (*a*) increase, (*b*) decrease in depth affect this pressure?

Experiment 2.

Place the funnel used in the last experiment at any point in the water, and mark by tying a thread around the tube the position of the water level in the U shaped tube. Now turn the funnel so that the membrane may face upwards, downwards, and in various directions, keeping the centre of the membrane at the same point all the time.

1. Is there any change in the water level in the U shaped tube?

2. What does this indicate with regard to the magnitude of the pressure in different directions on the membrane when it is kept at the same point?

6. Pressure at a Point.

By pressure at a point is meant the average pressure on an infinitely small area containing that point.

1. **The pressure at a point in a liquid increases with the depth.**

2. **The pressure at a point in a liquid at rest is equal in all directions.**

Experiment 3.

Lower into water a cylindrical tube A, having a movable bottom B, which is to be held in position by a string C (Fig. 65). When the tube has been lowered four or five inches into the water let the string go.

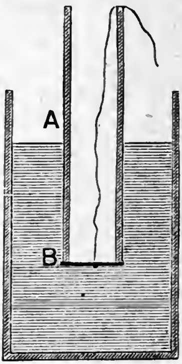


FIG. 65.

1. Why does the bottom not fall off?

2. Pour water into the tube. When does the bottom fall off? Why?

VII.—Surface of a Liquid at Rest Under the Action of Gravity.

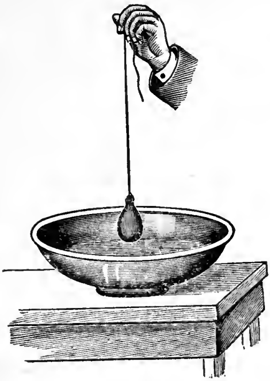


Fig. 66.

Experiment 1.

Pour enough mercury into a bowl or a dinner plate to cover its bottom. Hold a plumb-line over the surface of the mercury (Fig. 66).

1. What direction does a plumb-line always take?

2. What direction does the image of the line take with regard to the line itself?

3. What then must be the position of the surface of the mercury?

Experiment 2.

Pour water into a series of connecting tubes of various sizes and shapes. An apparatus for this purpose can be made by cutting the bottom off a glass bottle, inverting it and inserting tubes through a cork as shown in Fig. 67. Very small tubes should not be used.

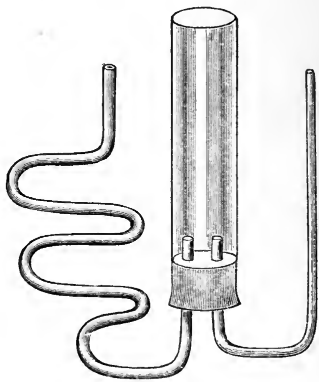


Fig. 67.

1. Does the water reach the same level in each tube?

2. What would be the result if some very small tubes were used?

The surface of a liquid at rest is horizontal.

VIII.—Buoyancy.

Experiment 1.

Lower several bodies, such as pieces of stone, iron, glass, wood, etc., into water by tying pieces of elastic to them (Fig. 68).

1. What change takes place in the tension of the elastic as the bodies enter the water?

2. What is the effect of the pressure of water on a body immersed, to lift it up or to depress it?

3. Why should the water produce this effect?

To answer this question consider:

(*a*) Which is the deeper in the water, the upper or the lower surface of the body?

(*b*) Upon which surface then will the pressure of the water be the greater?

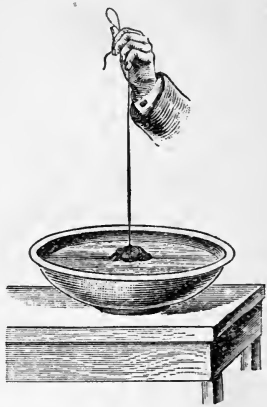


FIG. 68.

The resultant pressure exerted by a fluid on a body immersed in it is known as the **buoyancy** of the fluid.

7. What is the amount of the buoyant force which a liquid exerts on an immersed body.

Experiment 2.

To answer this question, take a brass cylinder A, which fits exactly into a hollow socket B. Hook the cylinder to the bottom of the socket and counterpoise them on a balance. Surround the cylinder with water (Fig. 69).

What change takes place in the equilibrium of the balance?

Now pour water into the socket until the equilibrium is restored.

1. When does this take place ?

2. How does the volume of the water in the socket compare with the volume of the cylinder ?

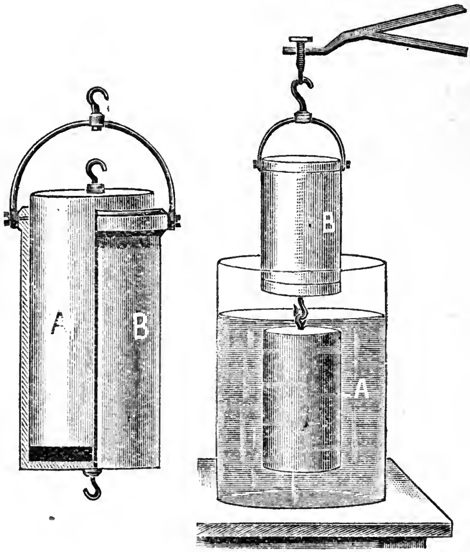


FIG. 69.

3. By the weight of what volume of water then was the cylinder buoyed up ?

4. Is the mutual attraction between the earth and A lessened by surrounding it with water ?

8. **Law of Buoyancy—Principle of Archimedes.**

The buoyant force exerted by a fluid upon a body immersed in it is equal to the weight of the fluid equal in volume to the body.

Or,

A body when weighed in a fluid loses in apparent weight an amount equal to the weight of the fluid which it displaces.

This is known as the **principle of Archimedes.**

9. **Flotation.**

Experiment 3.

Partially fill a graduated tube with water and place on the surface of the water in the tube a piece of wood which has been weighed.

1. What is the volume of the water displaced by the wood ?

2. What then is the weight of the water displaced by the wood ?

3. How does the weight of the wood compare with weight of the water displaced by it ?

4. To what is the buoyant force of water on the wood equal ?

5. When will a body sink ? when float ?

Experiment 4.

Try to float an egg on (*a*) fresh water, (*b*) a saturated solution of common salt.

1. What difference do you observe in the position of the egg ?

2. How does increase in the density of a liquid affect its buoyancy ? Why ?

3. Will a body whose density is one gram per cubic centimetre sink or float in water ? Why ?

QUESTIONS.

1. Why will an iron ship float on water while a piece of solid iron sinks?

2. Why do birds float high on water?

3. Why does oil float on water while mercury sinks?

4. Will air float on water?

5. Pour into the same test-tube (*a*) mercury, (*b*) a saturated solution of carbonate of potash in water, (*c*) alcohol coloured with a few drops of red ink, (*d*) coal oil. Cork the tube, shake it, and allow it to stand for a few seconds. What positions do the liquids assume? Why?

6. Release a cork which you are holding at the bottom of a vessel filled with water. What happens? Has the cork any power in itself to rise? If not, what causes the movement?

7. A cork which weighs 5 grams is tied to the bottom of a beaker which weighs 5 grams. If water weighing 50 grams is poured into the beaker, and the beaker and its contents placed on the scale pan of a balance, what weight placed in the other scale pan should balance it? Try.

8. A piece of coal is placed in one scale pan of a balance and iron weights are placed in the other scale pan to balance it. How would the equilibrium be affected if the balance, coal, and weights were now placed under water? Why?

9. A canoe and the person in it weigh 275 pounds, what weight of water is displaced by the canoe when floating with the person seated in it? If the person presses on one side of the canoe, what change will take place in the weight of the water displaced? Why?

10. What must be the weight of a piece of cork which will displace 10 grams of alcohol when floating on alcohol?

CHAPTER XII.

PROPERTIES AND LAWS OF GASES.

I.—Gaseous Pressure.

1. Weight.

Experiment 1.

Take a vessel A (Fig. 70), which can be attached to an air pump, weigh it, exhaust the air from it, close the stop-cock, and weigh it again.

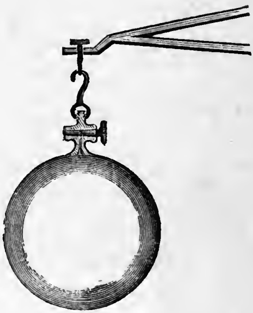


FIG. 70.

1. What difference in weight is observed?

2. What causes this difference?

Allow the air to re-enter and observe the result.

3. Has air weight?

Gases, like solids and liquids, possess weight.

2. Pressure due to weight.

We have seen that on account of their weight solids exert pressure on the bodies which support them, and liquids exert pressure on all bodies in contact with them. **Do gases exert pressure?**

Experiment 2.

Place a receiver on the plate of an air pump, and exhaust the air from the receiver (Fig. 71).

Try to separate the receiver from the plate.

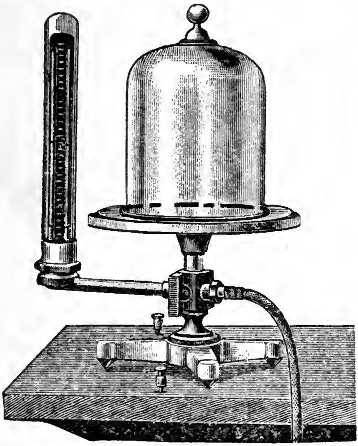


Fig. 71.

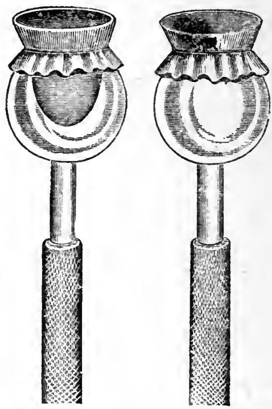


Fig. 72.

1. What evidence have you that the air on the outside of the receiver presses downward upon it?

2. What evidence have you that the air which was within the receiver exerted an upward pressure on it?

Experiment 3.

Tie a piece of sheet rubber over the mouth of a thistle-tube and exhaust the air from the tube by suction, or by connecting it by means of a piece of heavy rubber tubing with an air pump or an aspirator (Fig. 72).

1. What change takes place in the position of the rubber membrane?

2. What causes this change?

Turn the tube so that the membrane may face upwards, downwards, and in various directions.

1. Does the position of the membrane change as the tube is turned in different directions?

2. What does this prove with regard to the intensity of the pressure of the air in different directions at the same point?

3. Pressure due to the Expansive Force of a Gas.

We have seen (page 26) that gases tend to expand indefinitely, and that they consequently exert pressure on the surfaces of the vessels that contain them. This action may be illustrated by additional experiments.

Experiment 4.

Fill a bottle partly full of water, cork it with a per forated cork and connect it by a bent tube with an uncorked bottle, as shown in Fig. 73. Place both bottles under the receiver of an air pump and exhaust the air from the receiver.

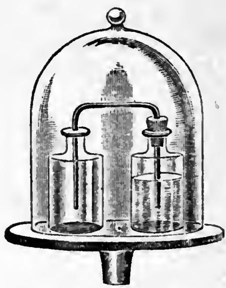


FIG. 73.

1. What movement takes place in the water?

2. What must have caused it?

3. Why did not this force cause the movement in the water before the air was exhausted from the receiver?

Let the air into the receiver again.

What takes place? Why?

Experiment 5.

Place a shrivelled apple under the receiver of the air pump and exhaust the air.

What change in the appearance of the apple takes place? Give a reason for it.

Experiment 6.

Place together the two hollow metal hemispheres, known as

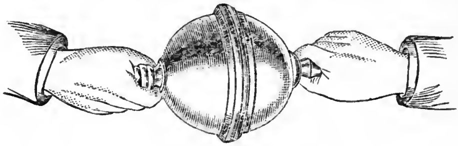


Fig. 74.

the Magdeburg hemispheres (Fig. 74), having carefully cleaned and greased the edges. Close the tap.

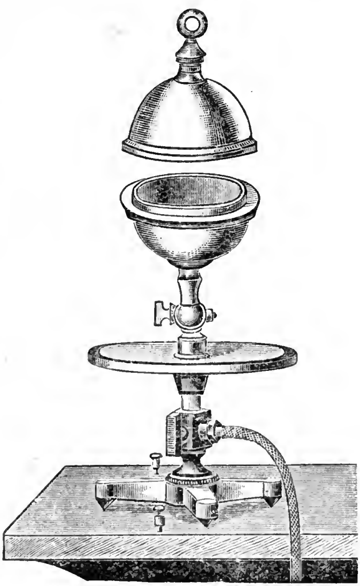


Fig. 75.

Has the air shut up within them any expansive force?

To answer this question, screw the apparatus to the air pump, open the tap, and exhaust some of this air (Fig. 75). Close the tap and try to separate the hemispheres.

1. What evidence have you now that the original air shut up within the hemispheres exerted an outward pressure upon their internal surfaces?

2. Why was this pressure not evident at first?

3. How does decreasing the density of a gas affect its expansive force, all other conditions remaining the same?

Experiment 7.

Take a long glass tube A closed at one end and fitted at the other with a stopcock which screws into the plate of an air pump. (The tube known as the Guinea-and-Feather tube answers well.) Stand the tubein a vertical position, with the open end of the tap in water (Fig. 76). Open the tap.

Does the water rise in the tube?

Take the tube out of the water, screw it to the air pump and partially exhaust the air, close the tap, unscrew it from the pump and place it as before in water. Open the tap.

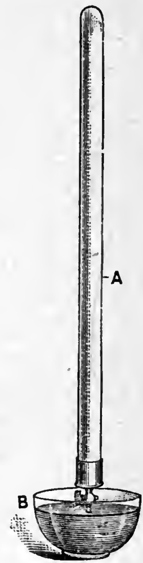


FIG. 76.

1. What is the cause of the movement in the water?

2. Did the pressure which caused this movement exist before the air was removed from the tube? If so, why did not the movement take place?

3. Is this pressure and the expansive force of the air within the tube equal when the water comes to rest? Give reasons for your answer.

4. When the tube was placed in the water and the tap opened, what change took place in (*a*) the density of the air remaining in the tube, (*b*) its mass, (*c*) its expansive force?

4. Buoyancy of Gases.

Experiment 8.

Hang a hollow metal or glass globe from one end of a short balance beam and attach a weight to the other end

of the beam to restore equilibrium. Place the balance under the receiver of an air pump and exhaust the air (Fig. 77).

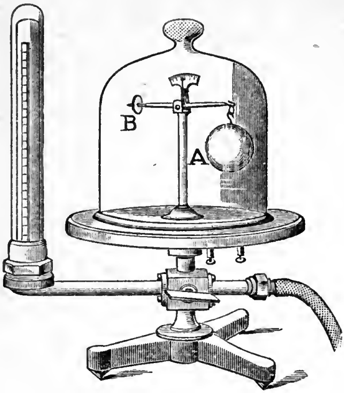


FIG. 77.

1. What change in the position of the balance beam takes place?

2. What effect must the air have had on the globe?

3. Did it have the same effect on the weight upon the other end of the beam?

4. Account for what takes place when the air is exhausted.

1. **Gases, like liquids, on account of their weight, exert pressure on the surfaces of bodies immersed in them, and this pressure is equal in all directions at the same point.**

For example, the gas (air) constituting the atmosphere, which surrounds the earth, on account of its weight presses down on the surface of the earth and upon everything on it, just as the water of the ocean presses down on the ocean bed and upon bodies resting on it.

2. **Gases, on account of their tendency to expand indefinitely, exert an expansive force, which is of equal intensity at all points both within the mass of the gas itself and upon the internal surface of the vessel which contains it.**

This pressure is sometimes known as the **tension** or **elastic force** of the gas

3. **A gas, like a liquid, exerts upon any body immersed in it a buoyant force which is equal to the weight of the gas displaced by the body.**

5. Measure of the Pressure of the Atmosphere.

The pressure of the atmosphere may be measured as other forces often are, by measuring some counterbalancing force (page 67).

Experiment 9.

Connect a glass tube A closed at one end with another B of the same size, but open at both ends, by a piece of stout rubber tubing C (Fig. 78). Each glass tube should be about 80 cm., and the rubber tube about 15 cm. in length and 4 mm. in diameter. Hold the tubes in the position shown at the left hand, and fill A and the rubber tube with mercury. Now invert A and place the connected tubes in the position shown at the right hand, thus forming a U shaped tube, of which the branches are A and B.

1. What is the length of the column of mercury in A above the level of the mercury in B?

The weight of this column of mercury is just balanced by the weight of the column of air pressing on the surface of the mercury in B. Hence the pressure of the air on the surface of the mercury in B may be measured by the weight of the mercury in A above the level of the mercury in B.

1. What is the length of the column of air which weighs the same as the column of mercury in A above the level of the mercury in B?

FIG. 78.

2. What transmits the air pressure on the surface of the mercury in B to column of mercury sustained by it?

3. If the tubes A and B were of different diameters, would the difference in levels of the mercury in the two tubes be the same as in this case, where the tubes are of equal diameter? Why?

An instrument for measuring the pressure of the atmosphere is called a **barometer.**

Instead of a U shaped tube like that used in the experiment above, a straight tube closed at one end, filled with mercury, and placed in a vertical position with the open end in a vessel of mercury, is more commonly employed (Fig. 79).

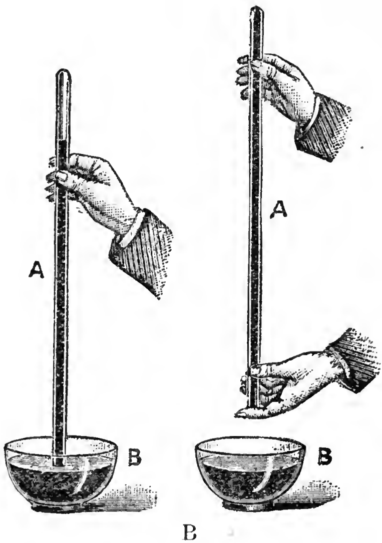


Fig. 79.

1. Upon what does the air press which sustains the column of mercury?

2. Would the height of this column be changed if the tube were not of uniform bore? Why?

3. What change in the height of the column would indicate an increase in the pressure of the atmosphere? What change a decrease? Why?

4. What is there in the tube above the mercury?

5. What effect would be produced by admitting a little air into this space? What force produces this effect?

II.—Compressibility of Gases.

We have seen (page 26) that gases are compressible. **What is the relation between the volume and the pressure of a gas?**

Experiment 1.

Take a tube about 25 cm. long and at least 4 mm. in diameter, one end of which is closed by a stopcock. A thistle-tube supplied with a stopcock answers well. Connect this by means of a heavy rubber tube not less than 50 cm. long with a glass tube, also about 50 cm. long. The joints should be wrapped with fine wire or string. Place the tube in a support as shown in Fig. 80, open the stopcock and pour mercury into the connected tubes until it reaches the same level at or near the centre of each glass tube. Close the stopcock. Take the reading of the barometer.

Height of barometer (H)= ?

The pressure to which the enclosed air is subjected is measured by

(1) The barometric reading (H)

when the mercury surfaces are at the same level. Why?

(2) The barometric reading (H)$\pm$ the difference between the levels of the mercury surfaces

when these surfaces are not at the same level. Why?

The plus sign is to be taken when the mercury in the open

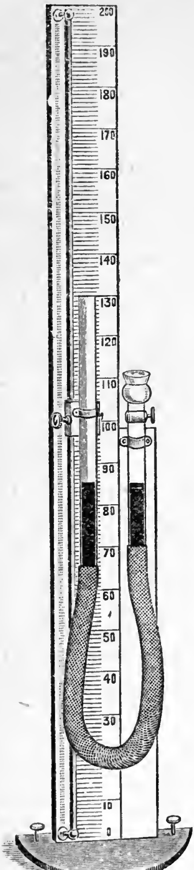


FIG. 80.

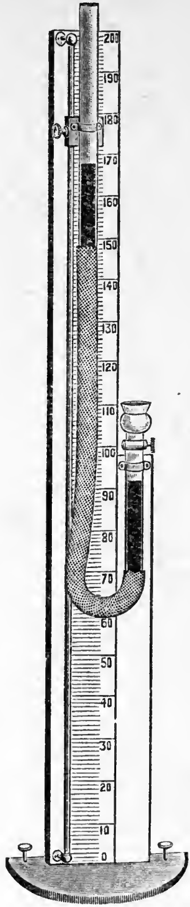


FIG. 81.

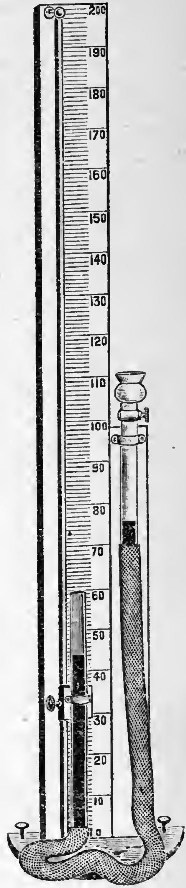


FIG. 82.

tube is higher, and the minus sign when it is lower than in the closed tube. Why?

Place the open tube in several positions with the surface of the mercury in it either above (Fig. 81) or below (Fig. 82) the surface of the mercury in the closed tube; and measure

(1) The lengths of the air column in the closed tube.

(2) The vertical distances between the mercury levels in the two tubes.

Supposing that V represents the original volume of the enclosed air and H the reading of the barometer; and that V_1, V_2, V_3, V_4, etc., represent the volumes of this air at successive observations; and that H_1, H_2, H_3, H_4 represent the differences in mercury levels for these observations, fill up the following table:

VOLUMES.	PRESSURES.	PRODUCTS.
$V =$	$P = H \quad =$	$V \times P =$
$V_1 =$	$P_1 = H \pm H_1 =$	$V_1 \times P_1 =$
$V_2 =$	$P_2 = H \pm H_2 =$	$V_2 \times P_2 =$
$V_3 =$	$P_3 = H \pm H_3 =$	$V_3 \times P_3 =$
$V_4 =$	$P_4 = H \pm H_4 =$	$V_4 \times P_4 =$
Etc.	Etc.	Etc.

If the experiment is carefully performed, the products $V \times P$, $V_1 \times P_1$, etc., will be found to be equal. This being the case, it is evident that the volume of the air is decreased at exactly the same rate as the pressure is increased, or is increased at the same rate as the pressure is decreased. That is, the volume of a given portion of air varies inversely as the pressure to which it is subjected.

The extended researches of careful experimenters have shown that all gases, within certain limitations, conform to this law.

The law is known as Boyle's or Mariotte's Law. It may be thus stated :

6. **Boyle's or Mariotte's Law.**

If the temperature is kept constant, the volume of a given mass of gas varies inversely as the pressure to which it is subjected.

The gases which most closely follow this law are those which are farthest removed, both as to temperature and pressure, from their points of liquefaction.

When a gas nears its liquefying point, the reduction in volume is greater than that which the law would indicate.

QUESTIONS.

1. If the volume of the air shut up in the tube, Experiment 1, page 123, is 10 c.cm. when the mercury is at the same level in each tube and the barometer stands at 70 cm., what will be the difference in level between the surfaces of the mercury in the tubes when the volume of this air occupies (*a*) 5 c.cm., (*b*) 20 c.cm.?

2. The differences in levels, Experiment 1, page 123, at four different observations are 10 cm., 90 cm., 170 cm., 250 cm., and the volume of the enclosed air at the first observation was 12 c.cm., what was the volume of the air at each of the other observations if the barometer stands at 70 cm.?

3. What effect would (*a*) raising, (*b*) lowering, the open tube, Experiment 1, page 123, have upon (1) the mass, (2) the density, (3) the expansive force of the enclosed air ?

4. The pressure of a gas is 10 grams per sq. cm. when its volume is 100 c.cm., what is the pressure when the volume is 150 c.cm.?

5. The volume of gas shut up in a rubber bag is 200 c.cm. when the barometer stands at 70 cm., what will be the volume of the gas when the barometer stands at 80 cm.?

6. If a gas occupies a volume of 25 c.cm. when the barometer stands at 76 cm., what must be the reading of the barometer when the gas measures 30 c.cm.?

7. A gas holder contains 22·4 litres of a gas measured when the barometer stands at 72 cm., what will be the volume of the gas when the barometer stands at 76 cm.?

8. A rubber bag contains 100 c.cm. of air at the atmospheric pressure, what will the volume of the air become if the bag is sunk to a depth of 30 feet in water? What would be the buoyant force of the water upon it? The water barometer stands at 30 feet.

CHAPTER XIII.

SOLUTION, DIFFUSION, OCCLUSION.

I.—Solution.

1. Solids in Liquids.

Experiment 1.

Place 15 grams of powdered potassic chlorate in a beaker containing 50 c.cm. of water at the temperature of the class room. Stir the mixture for a few minutes.

Has the salt disappeared ?

If not, fold and cut a filter paper as shown in Fig. 83, place it in a funnel, pour the mixture into it, and collect the liquid passing through the filter paper (the filtrate) in another beaker.

FIG. 83.

1. Can you **see** any of the salt in the filtrate ?
2. Does this liquid contain any of the salt ?

To answer this question,

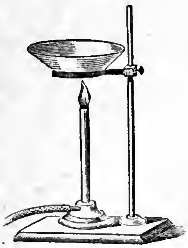


FIG. 84.

(1) Carefully remove the salt from the filter paper, and, when dry, weigh it.

1. Is all the salt present ?
2. If not, where must the remainder be ?

(2) Place the filtrate in an evaporating dish (a saucer will answer), and evaporate the water by gently heating the dish over a spirit lamp or Bunsen burner (Fig. 84).

1. What remains when the water has disappeared ?
2. How do you account for the fact that this substance was invisible in the water ? (See page 27.)

Experiment 2.

Repeat Experiment 1, placing the same quantity of the potassic chlorate in the same quantity of boiling water.

How does increase in temperature affect the solution of this salt in water?

Experiment 3.

Place 15 grams of common salt in 50 c.cm. of water at the temperature of the class room. Stir the mixture.

Which is the more soluble in cold water, potassic chlorate or common salt?

Experiment 4.

Place 5 grams of barium sulphate in 50 c.cm. of water, stir the mixture, filter, and evaporate the filtrate. Weigh the salt remaining on the filter paper.

Is barium sulphate soluble in water?

Experiment 5.

Place a crystal of iodine in a test-tube partly filled with water. Cork the tube and shake it.

Is the iodine soluble in water?

Uncork the tube, add two or three cubic centimeters of chloroform, cork it again, and shake. Allow the tube to stand for a few seconds.

1. Describe what has taken place.

2. Account for (*a*) the colour of the lower liquid, (*b*) the relative positions of the liquids.

The solution of a solid in a liquid is dependent on—

1. **The nature of the solid and of the solvent.**
2. **The temperature.**

As a usual thing, the higher the temperature the greater is the quantity of the solid held in solution.

2. Gases in Liquids.

Experiment 6.

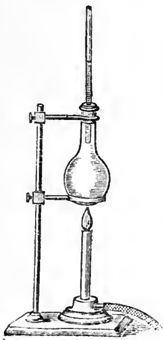


FIG. 85.

Fill a flask with water and insert a perforated rubber cork. See that there is no air under the cork. Push a glass tube through the cork so that the lower end is below the surface of the water in the flask (Fig. 85). Heat the water.

1. What collects at the surface of the water under the cork?

2. Where did it come from?

3. How does increase in temperature affect the solubility of the gas in water?

Experiment 7.

Arrange apparatus as in Fig. 86. Into the flask B pour 10 c. cm. of strong liquor ammoniæ. Open the stopcock, fit the cork into B, but leave flask A uncorked as shown. Gently heat B. When A is filled with ammonia gas, which will be known by the strong odour observed when it escapes into the room, remove the cork from B, shut the stopcock, pour about a tablespoonful of water into A, and place the cork in it **at once**. Dip the free end of the tube into water (Fig. 87) and open the stopcock.

1. What takes place? Give the reason.

2. What becomes of the gas that was in the flask A?

3. Which is the more soluble in water, ammonia gas or air? How do you know?

Experiment 8.

Partly fill a beaker with water, place it under the receiver of an air pump and exhaust the air from the receiver.

1. What do you observe to collect on the sides of the beaker?

2. Is the pressure to which the water is subjected increased or decreased by removing the air from the receiver?

3. What is the relation between pressure and the amount of gas held in solution by a liquid?

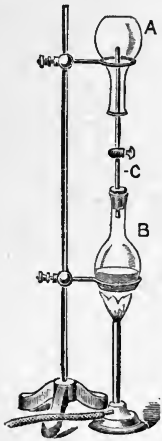


FIG. 86.

FIG. 87.

Experiment 9.

Repeat Experiment 8, using liquor ammoniæ instead of water.

Describe what takes place. Explain the reason.

The solution of a gas in a liquid is dependent on—

1. **The nature of the gas and of the solvent.**

2. **The temperature; the higher the temperature the less the quantity of gas held in solution.**

3. **The pressure; the higher the pressure the greater the quantity of gas held in solution.**

II.—Diffusion.

4. Free Diffusion of Liquids.

Experiment 1.

Fill a glass jar of the form shown in Fig. 88 about two-thirds full of water, and by means of a thistle-tube introduce beneath the mass of the water one-third as much of a concentrated solution of copper sulphate. Allow the jar to stand undisturbed for a few days. Observe it from time to time.

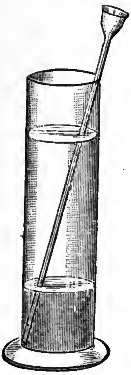


FIG. 88.

Experiment 2.

Partially fill a test-tube with a solution of blue litmus, and pour into a thistle-tube which reaches the **bottom** of the test-tube a few drops of sulphuric acid. Let the tube stand for a few days and observe from time to time the position of the upper surface of the lower liquid.

(To show the action of sulphuric acid when mixed with the solution of litmus, add a drop of the acid to some of the solution in another tube and stir the mixture.)

1. Is the bounding surface between the liquids in the jar (Experiment 1) and in the tube (Experiment 2) sharply defined at first?

2. Describe what you observed to take place in each case when the tubes were allowed to stand.

This intermingling of liquids in contact with one another is known as **free diffusion.** It is probably due to the constant movement of the molecules from place to place throughout the mass of the fluid.

Will any liquid diffuse through any other? Try coal oil and water, water and mercury.

Substances differ widely in their rates of diffusion. Solids, which when in solution diffuse rapidly, are usually crystalline in structure, and hence are known as **crystalloids**; while those which diffuse slowly are usually amorphous in structure, and are known as **colloids.** To the latter class belong such bodies as starch, gelatine, albumen, and gummy substances generally.

4. Diffusion of Liquids through a Membrane—Osmose.

Experiment 3.

Tie a piece of moistened parchment paper or other animal membrane (a piece of bladder answers well), over the funnel of a thistle-tube. Fill the funnel and part of the tube with a concentrated solution of copper sulphate, and support it, as shown in Fig. 89, in a vessel of water, so that the water on the outside may reach the same level as the solution on the inside of the tube. Set it aside for two or three hours, and observe from time to time the height of the liquid in the tube.

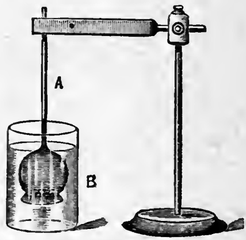


FIG. 89.

1. What change has taken place in the height of the solution in the tube ?

2. What change has taken place in the water ?

3. How do you know (*a*) that water has passed into the tube, (*b*) that the copper sulphate solution has passed out of it ?

4. Which is the greater, the quantity of the water passing into the tube or the quantity of the solution passing out of it ? How do you know ?

This intermingling of liquids by forcing their way through membranes is known as **osmose.**

5. Dialysis.

The unequal diffusibility of different substances through membranes is taken advantage of by the chemist for the purpose of separating bodies that are mixed. The process is called **dialysis.** The dialyser is a wooden or hard rubber hoop, over one end of which is stretched (as shown in Fig. 90), while wet, a piece of parchment paper. The

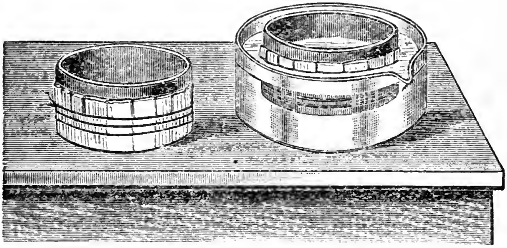


FIG. 90.

mixed solution to be dialysed is placed in the vessel thus formed, and this vessel is floated on pure water contained in another vessel. In a few days the liquids are more or less completely separated, the greater part of the more diffusible one having passed out into the water.

Experiment 4.

Separate a mixed solution of common salt and starch.

Make a dialyser by cutting off a large bottle three or four inches below the neck and making a bottom by tying parchment paper over the open end. Place in this vessel the mixed solution, and suspend it, as shown in Fig. 91, in a vessel containing water, for a few days.

1. Is there any salt in the water in the vessel ?

To answer this question, add to a little of the water a few drops of silver nitrate solution. If salt is present a white precipitate will be formed.

2. Is there any of the starch in the water in the vessel?

To answer this question, add to a little of the water a crystal of iodine. If starch is present, the water will be turned a deep blue colour.

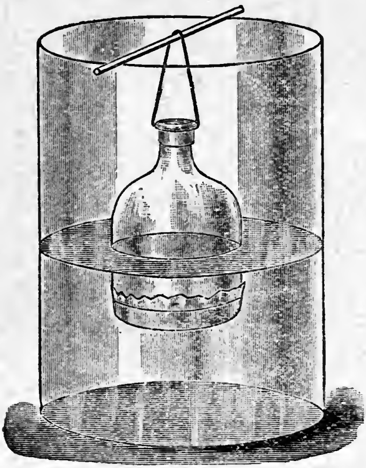


Fig. 91.

6. Free Diffusion of Gases.

Experiment 4.

Pour a little liquor ammoniæ into an evaporating dish and warm the dish over a spirit lamp or Bunsen burner.

What evidence have you that ammonia gas has mingled with the air?

This experiment is illustrative of the free diffusion of gases. Any gas will diffuse readily through any other, probably because the molecules of one gas, in their free motion, pass easily into the spaces between the molecules of the other gas.

7. Diffusion of Gases Through a Porous Partition.

Experiment 6.

Arrange apparatus as in Fig. 92. A is a porous battery-cell, B a glass tube fitted into a perforated rubber cork inserted into the cell, C is a bent tube containing water (a calcium chloride or thistle-tube answers well for this purpose). The large branch of the tube is connected with B by means of a perforated cork, and the end of the small branch is drawn out into a jet. Place on the outside of the porous cell a glass jar D, and fill it with hydrogen gas. This may be prepared by pouring water acidulated with about one-tenth its volume of sulphuric acid over some zinc clippings placed in a flask E. The hydrogen will pass up through the tube F and fill the jar D. Since the air is denser than the hydrogen its buoyancy will cause the hydrogen to remain in the jar.

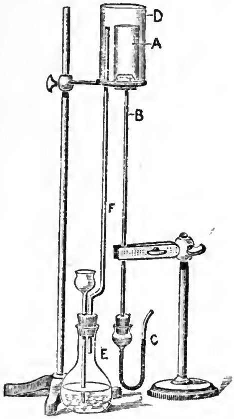


FIG. 92.

1. What evidence have you that additional pressure is being exerted on the surface of the water in the large branch of C?

This increased pressure arises from the fact that the hydrogen passes more rapidly through the pores into the porous cell than the denser air passes out of it.

2. Remove the bottle containing the hydrogen. What change takes place in the water levels in the tube C? Why?

Experiment 7.

Arrange apparatus as shown in Fig. 76. A is a porous battery-cell, B a bent glass tube fitted into a perforated

rubber cork inserted into the cell. The lower end of B dips into water in a vessel C. Fill a wide mouthed jar D with carbon dioxide, a gas which is denser than air. This may be done by placing a teaspoonful of baking soda or washing soda in the bottom of the jar and covering it with acidulated water. Place the porous cell in the jar, keeping it above the liquid, as shown in the figure. Observe the water in the tube B.

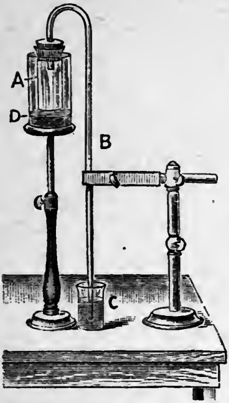


FIG. 93.

1. What takes place? Why?

2. What should take place if the jar containing the carbon dioxide were removed? Try.

3. What change now takes place in the water levels Explain.

8. Diffusion of Gases Through a Membrane.

Experiment 8.

Repeat Experiment 6 above, placing in the hydrogen the thistle-tube used in Experiment 3, page 133, instead of the porous cell. Connect the thistle-tube with a pressure guage. (Fig. 94).

What change takes place in the water levels in the guage? Explain.

Remove the hydrogen jar. What results? Why?

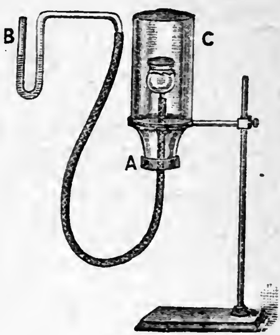


FIG. 94

Experiment 9.

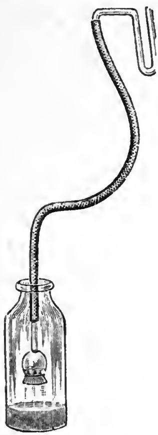


FIG. 95.

Repeat Experiment 8, using carbon dioxide gas instead of hydrogen (Fig. 95).

What is the cause of the differences in pressure indicated by the guage?

The above experiments prove that the rapidity of diffusion of a gas depends on its density. The greater the density of a gas the less is its rate of diffusion. Exact experiments conducted by Loschmidt, who has investigated the phenomena of free diffusion, and by Graham, who has investigated the phenomena of diffusion through porous septa, have established the following law.

9. Law of Diffusion of Gases.

The relative rates of diffusion of gases are inversely proportional to the square roots of their densities.

For example, the densities of oxygen and hydrogen are in the ratio, 16 : 1, and their rates of diffusion are in the ratio, 1 : 4, that is, $\sqrt{1} : \sqrt{16}$.

The diffusion of gases is of great importance in the economy of nature. If gases would float on one another, as oil on water, or water on mercury, the present forms of life could not exist. The requisite proportion of nitrogen to ogyxen in the air would not be maintained, and the noxious gases exhaled by animals and generated by the decomposition of organic matter would collect in dangerous proportions at the earth's surface.

III.—Occlusion.

Experiment 1.

Heat a piece of charcoal to redness in a flame, allow it to cool, and introduce it into a tube, filled with ammonia gas as in Experiment 9, page 131. Place the tube in a vertical position with its open end in mercury (Fig. 96).

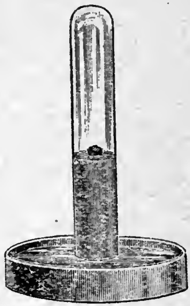


FIG. 96.

What change takes place in the volume of the gas in the tube?

For various reasons it is believed that the gas absorbed by the charcoal is condensed on its surface. All solids appear to possess to a greater or less extent this power of condensing gases on their surfaces.

The amount of the condensed gases is dependent on

1. The area of the surface of the solid.

A small piece of charcoal, on account of its porous condition, presents a very large surface to a gas in which it is placed.

2. The nature of the solid and of the gas.

Charcoal condenses about twice as much ammonia as it does carbon dioxide on the same surface.

Certain metals, especially platinum and palladium, possess this power in a high degree.

3. **The Temperature.**

The absorption of a gas by a metal has received the name of **occlusion.**

The efficiency of charcoal as a deodorant and disinfectant is probably due to the action of the **oxygen condensed in its pores upon the noxious gases.**

CHAPTER XIV.

SPECIFIC GRAVITY.

I.—Relation between Specific Gravity and Density.

The specific gravity of a body is the ratio of its weight to the weight of an equal volume of water at 4° C.

$$\text{Or specific gravity of a body} = \frac{\text{its weight}}{\text{weight of an equal volume of water}}$$

We have seen that the density of a body is the mass of a unit volume of it. In the C. G. S. system of units, since the cubic centimeter is the unit of volume and the gram the unit of mass, and one cubic centimeter of water has a mass of one gram, the number expressing the density of a body will also indicate its specific gravity. For example, the specific gravity of gold is 19.36; that is, a piece of gold weighs 19.36 times as much as the same volume of water; but the density of water is one gram per cubic centimeter, therefore the density of gold is 19.36 grams per cubic centimeter.

While the numbers are the same it should be remembered carefully that the measure of the density is the number of units of mass (grams) in a unit of volume (cubic centimeter), and the specific gravity of a body is the number of times the weight of any volume of the body contains the weight of the same volume of water.

II.—To Find the Specific Gravity of a Solid.

1. To Find the Specific Gravity of a Solid Heavier than Water.

Method I.

Experiment 1.

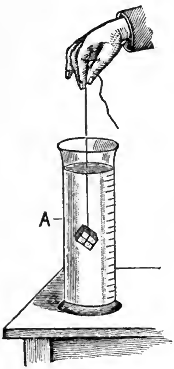


FIG. 97.

Weigh a piece of lead.

Weight (W) = gm. ?

Tie a thread to it and sink it in a graduated tube partially filled with water (Fig. 97). Observe the volume of the water displaced by it.

Volume (V) = c.cm. ?

But 1 c.cm. of water weighs 1 gram.

Therefore V gm. = weight of water equal in volume to the wood.

$$\text{Specific gravity of lead} = \frac{\text{its weight}}{\text{weight of equal volume of water.}}$$

$$= \frac{W}{V} = \ ?$$

If the solid is soluble in water another liquid in which it is not soluble may be used in the graduated tube.

Method 2.

Experiment 2.

Weigh an iron nail in air.

Weight (W)= ?

Tie a thread to it, suspend it from the scale pan of a balance and weigh it when surrounded with water (Fig. 98).

Weight (W_1) = ?

Therefore $W - W_1$ = the loss in weight in water.
= the buoyancy of the water
= the weight of water equal in volume to the nail (page 112).

But the specific gravity of a body

$$= \frac{\text{its weight}}{\text{weight of an equal volume of water.}}$$

Therefore the specific gravity of the nail

$$= \frac{\text{its weight}}{\text{loss of weight in water,}}$$

$$= \frac{W}{W - W_1} = \ ?$$

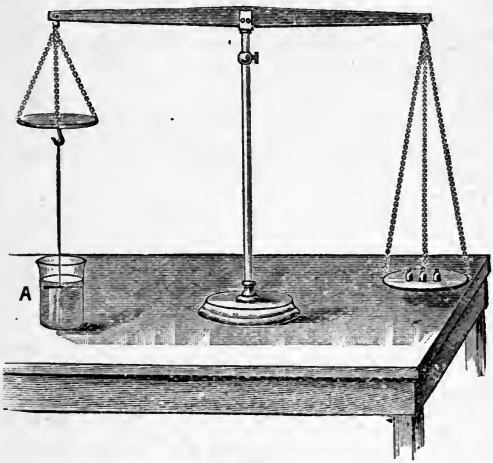


FIG. 98.

Experiment 3.

Find in the same way the specific gravities of pieces of glass, lead, rock, etc.

If the solid is soluble in water, its specific gravity may be obtained by finding, as above, the ratio of its weight to that of an equal volume of some liquid in which it is not soluble, and then multiplying the result by the specific gravity of this liquid.

2. To Find the Specific Gravity of a Solid lighter than Water.

Method 1.

Experiment 4.

Weigh a piece of wood.

Weight (W) = gm. ?

By means of a needle, or a piece of fine wire, sink it in a graduated tube partially filled with water (Fig. 99). Observe the volume of the water displaced by it.

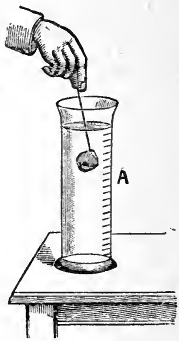


FIG. 99.

Volume (V) = c.cm. ?

But 1 c.cm. of water weighs 1 gram.
Therefore V gm. = weight of water equal in volume to the wood.
Specific gravity of the wood

$$= \frac{\text{its weight}}{\text{weight of an equal volume of water}},$$

$$= \frac{W}{V} = \ ?$$

If the solid is soluble in water, another liquid in which it is not soluble may be used in the graduated tube.

Method 2.

Experiment 5.

Weigh a piece of wood.

Weight (W) = ?

Tie a piece of lead to the wood and weigh the two together when surrounded with water.

$$\text{Weight } (W_1) = \quad ?$$

Now weigh the lead alone when surrounded with water.

$$\text{Weight } (W_2) = \quad ?$$

Then $W_1 - W_2$ = the weight of the wood alone in water, and

$$W - (W_1 - W_2) \text{ or } W - W_1 + W_2$$

= the loss of weight in the wood when weighed in water.

$$\text{Specific gravity of the wood} = \frac{\text{its weight}}{\text{loss of weight in water}}.$$

$$= \frac{W}{W - W_1 + W_2} = \quad ?$$

Experiment 6.

Find the specific gravities of pieces of oak, pine, and cork, etc., by methods 1 and 2.

3. To Find the Specific Gravity of a Powder.

Experiment 7.

Find the specific gravity of a sample of sand. Weigh the sand.

$$\text{Weight } (W) = \quad ?$$

Counterpoise on a balance a specific gravity bottle, that is, a bottle which, when filled to a certain mark, contains a known weight of water, say m grams (Fig. 100).

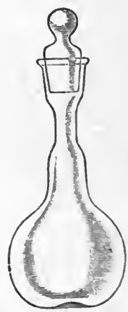


FIG. 100.

Introduce the sand into the bottle, and fill the remaining space in the bottle with water. Weigh the water and sand in the bottle.

$$\text{Weight } (W_1) = \quad ?$$

Let x = the weight of water displaced by the sand.

Then $m - x$ = weight of water in the bottle.

But W_1 = weight of water + weight of sand,

or $W_1 = m - x + W$.

Therefore $x = W + m - W_1$

= weight of water equal in volume to the sand.

The specific gravity of the sand

$$= \frac{\text{its weight}}{\text{weight of an equal volume of water.}}$$

$$= \frac{W}{W + m - W_1} = ?$$

III.—To Find the Specific Gravity of a Liquid.

Method 1.

4. By the Specific Gravity Bottle.

Fig. 101.

Specific gravity bottles are of various forms. Figure 101 shows one of the most common. It is a small glass bottle, with a perforated glass stopper, made to contain a definite weight of water when filled and the stopper inserted. Figure 100 shows another form of the bottle.

Instead of a bottle, a pipette with a very fine bore, graduated to contain a definite volume, say 10 c cm., may be used for rapid determinations of specific gravities. It may be supported on the scale pan of a balance by a wire support (Fig. 102).

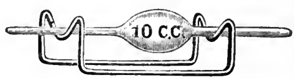


Fig. 102.

Experiment 1.

Counterpoise on a balance a specific gravity bottle which is made to contain a definite weight (m) of water. Fill it with alcohol and weigh the alcohol.

$$\text{Weight (W)} = \quad ?$$

The volume of the alcohol is the same as the volume of the water which fills the bottle.

Specific gravity of alcohol

$$= \frac{\text{its weight}}{\text{weight of an equal volume of water.}}$$

$$= \frac{W}{m} = \quad ?$$

Experiment 2.

Find in the same way the specific gravities of samples of vinegar and coal oil.

5. By the Common Hydrometer.

Experiment 3.

Make of hard wood a rectangular rod 1 sq. cm. in section and 20 cm. long. Mark off on one of its long faces a centimeter scale (Fig. 103). Bore into one end a hole to the

FIG. 103.

depth of several centimeters. Fill the hole with a sufficient weight of shot to cause the rod to float vertically in water. Close the hole with plaster of Paris or cement. Place the rod, with the weighted end down, in a vessel containing water (Fig. 104).

1. How deep does it sink in water?

2. How many cubic centimeters of water does it displace?

3. How many grams of water does it displace?

4. What is the weight of the rod? (Page 113.)

Now place the rod in the same position in alcohol.

1. How many cubic centimeters of alcohol does it displace?

2. How does the weight of the rod compare with weight of the alcohol displaced?

3. What then must be the weight of the number of cubic centimeters of alcohol displaced by the rod?

4. What, therefore, is the weight of one cubic centimeter of alcohol?

5. What is the specific gravity of the alcohol?

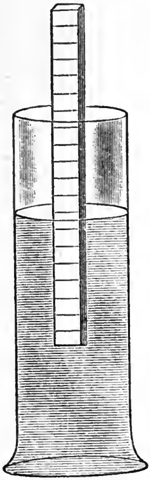


FIG. 104.

From the above reasoning it is seen that **when the same body floats in different liquids the volumes of the liquids displaced by it are inversely proportional to their specific gravites.**

Instead of a rod constructed as described, an instrument called a hydrometer is generally employed to take advantage of this principle in determining the specific gravities of liquids.

The **common hydrometer** consists of a hollow sphere or cylinder A, to which is attached on one side a slender graduated stem B, and on the other side a small sphere C, loaded to cause the instrument to float vertically in a

liquid (Fig. 105). The weight and volume are so adjusted that the instrument sinks to the division mark at the lower end of the stem in the most dense liquid to be investigated, and to the division mark at the upper end of the stem in the least dense liquid. The scale on the stem indicates the specific gravities of liquids between these limits.

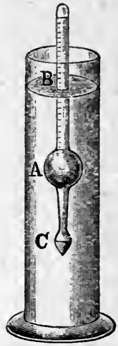


FIG. 105.

As the range of an instrument of this class is necessarily limited, special instruments are constructed for special liquids. For example, one instrument is used for determining the specific gravities of milks, another for petroleum oils, another for alcohols, etc.

1. If a body when floating in water displaces 10 c.cm., what is the density of a liquid in which when floating it displaces 15 c.cm.?

2. If the specific gravity of pure milk is 1·086, what is the specific gravity of a mixture containing 500 c.cm. of pure milk and 100 c.cm. of water?

3. A body weighing 10 grams has attached to it a piece of lead, and the two together when submerged displace 50 c.cm. of water. The lead alone displaces 10 c.cm. What is the density of the body?

4. If the specific gravity of gold is 19·36 and that of silver is 10·5, what is the specific gravity of a lump made up of 38·72 grams of gold and 31·5 grams of silver?

5. A hydrometer floats with $\frac{3}{4}$ of its volume submerged when floating in water and $\frac{2}{3}$ of its volume submerged when floating in another liquid. What is the density of this liquid?

6. A body which weighs 10 grams in air, has a sinker attached to it and the two together weigh 20 grams in water. The sinker alone weighs 30 grams in water. What is the density of the body?

6. By Balancing Columns of Liquids.

Experiment 4.

Find the specific gravity of a solution of common salt.

Take two glass tubes, *a* and *b*, each about 75 cm. in length and of the same size, connect them with a T tube, to which is attached a piece of rubber tubing (Fig. 106). Place the lower end of one tube in water and that of the other in the salt solution. Support the tubes in a vertical position. By suction upon the rubber tube draw the liquids part way up into the glass tubes. Close the rubber tube with a clamp.

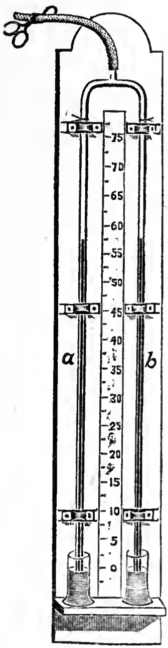


FIG. 106.

Observe the heights of the liquids in the tubes above the surfaces of the liquids in the vessels.

1. What force supports the weight of the liquid in each tube?

2. How does the weight of the water in one tube compare with the weight of the salt solution in the other?

3. How does the volume of the water in one tube compare with the volume of the salt solution in the other?

4. What is the specific gravity of the salt solution?

5 Is it necessary that the tubes *a* and *b* should be of the same size?

7. By Weighing a Solid in the Liquid and in Water.

Experiment 5.

Find the specific gravity of glycerin.

Weigh a piece of iron.

$$\text{Weight } (W) = \quad ?$$

Weigh the iron immersed in water.

$$\text{Weight } (W_1) = \quad ?$$

Weigh the iron immersed in glycerin.

$$\text{Weight } (W_2) = \quad ?$$

Then $W - W_1$ = weight of water displaced by iron

and $W - W_2$ = weight of glycerin displaced by iron.

But the volume of the water displaced by the iron equals the volume of the displaced glycerin.

$$\text{Specific gravity of glycerin} = \frac{W - W_2}{W - W_1} = \quad ?$$

Experiment 6.

Make a solution of alcohol and water such that beeswax will just float in it totally immersed. Find the specific gravity of the solution and from it determine the specific gravity of the wax.

Experiment 7.

Find the specific gravity of a sample of milk. Mix this milk with water in the ratio of two volumes of milk to one of water. Find the specific gravity of the mixture. Test your result by theory.

IV.—To Find the Specific Gravity of a Gas.

The specific gravities of gases may be determined by means of a large, light specific gravity bottle fitted with a stopcock which can be screwed to an air pump. The air is exhausted from the flask, and the flask counterpoised on a balance. It is then filled with the gas whose specific gravity is to be determined, at a set temperature and pressure, and the gas is weighed. This weight is compared with the weight of a bottleful of the standard with which the gas is to be compared. This standard is frequently air at 0° C. and 76 cm. barometric pressure instead of water.

Why must the temperature and the pressure be noted in finding the specific gravity of a gas?

CHAPTER XV.

NATURE AND SOURCES OF HEAT.

I.—Nature of Heat.

We have seen, page 40, that heat is one of the forms in which energy becomes known to us. Its nature is not perfectly understood; but since most of the phenomena connected with it may be explained by this theory, *heat is believed to be the energy possessed by a body in virtue of the motion of its molecules.*

II.—Sources of Heat.

Heat is regarded as a form of energy because its sources are other forms of energy, and it in turn may be transmuted into other forms.

The following are some of its sources:

1. Heat from Mechanical Action.

(1) From Friction.

Experiment 1.

Rub a button on a piece of cloth.

1. What evidence have you that it has received heat?
2. Why does iron when filed become hot?
3. Why is oil placed in the journals of car axles?

4. If a small brass tube is filled with water, corked, and then made to rotate rapidly while it is squeezed between two pieces of wood, it will receive sufficient heat to cause the water to boil and to eject the cork. Explain the reason.

(2) From Percussion.

Experiment 2.

Place a piece of lead on a block of iron and strike it a few blows with a hammer.

1. What evidence have you that it has received heat ?

2. What has become of the energy of bodily onward motion that was in the hammer ?

3. A bullet is fired against an iron target and is picked up almost too hot to be held in the hand. Explain the reason.


Fig. 107.

(3) From Compression.

Experiment 3.

Place a piece of tinder in a tube (Fig. 107) closed at one end and containing air. Push a piston into it quickly.

1. What takes place ? Explain the reason.

2. Why do air-pumps become heated when compressing air into the pneumatic tires of bicycles ?

2. Heat from Chemical Action.

Experiment 4.

Pour 100 c.cm. of water into a beaker, and carefully stir into it 10 c.cm. of sulphuric acid.

What evidence have you of the generation of heat ?

Experiment 5.

Cut a thin shaving from the end of a stick of phosphorus, dry it with blotting paper, put it on a plate, and place on it some powdered iodine. Neither the phosphorus nor the iodine should be touched with the fingers. The phosphorus should be held in forceps and cut under water. The iodine

may be placed on a piece of paper and poured on the phosphorus.

What takes place?

Most chemical changes are accompanied by changes in the quantities of heat possessed by the bodies taking part in them. This is the source of the heat resulting from combustion, which is but a particular case of chemical action.

3. Heat from an Electric Current.

Experiment 6.

Connect three or four Bunsen or Grenet cells as shown in Fig. 108. Attach a copper wire to each pole, and complete the circuit by attaching to the free end of one of the copper wires a piece of fine platinum or iron wire four or five inches

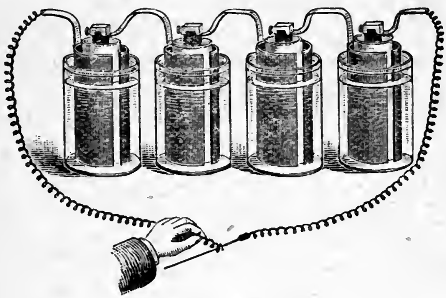


FIG. 108.

long, and touching the end of the other copper wire to the end of the platinum or iron wire. (The fine iron wire used by florists answers well.) Slide the copper wire along the iron wire up towards the other copper wire.

What evidence have you of the production of heat?

Whenever an electric current meets with resistance in a conductor heat results. The fine iron wire offers considerable resistance, and if a sufficiently strong current be made to pass through it, the wire will become white hot and burn up.

How are the filaments in incandescent electric lamps heated?

The relation between heat and the energy of an electric current will be more fully discussed under **Electricity**, Part II.

4. Heat from Radiant Energy from the Sun.

This is by far our most important source of heat. We shall consider at a later stage the theory regarding the transmission of the sun's heat to us in the form of **Radiant Energy.**

In the following chapters we shall discuss some of the **effects** of heat, viz.: **expansion, change of temperature,** and **change of state.**

CHAPTER XVI.

EXPANSION THROUGH HEAT.

1. In Solids.

Experiment 1.

Take a brass ball and ring (Fig. 109), such that ordinarily the ball will just pass through the ring. Heat the ball intensely in the flame of a Bunsen burner and try to pass it through the ring.

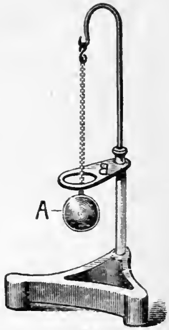


Fig. 109.

1. What change has taken place in the volume of the ball?

2. Will it pass through the ring when it has cooled?

3. How could you make the ball pass through when hot?

Experiment 2.

Arrange apparatus as in Fig. 110. A metal rod is fixed at

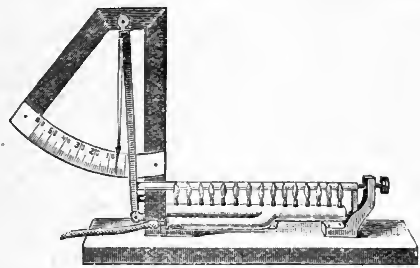


Fig. 110.

one end while the other presses against a compound lever so arranged that the slightest elongation of the rod is indicated

on a scale. Apply heat to the rod and watch the end of the pointer on the scale.

1. What do you observe?
2. What does the experiment prove?
3. Allow the rod to cool, and what is the result?

Experiment 3.

Prepare a compound bar made up of two strips, one of iron and the other of copper, riveted together as shown in Fig. 111 Heat this bar strongly in the flame of a Bunsen burner.

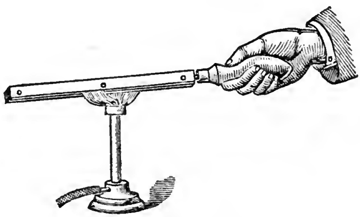


FIG. 111.

1. What is the result?
2. Which metal is on the concave side?
3. Which metal is the more elongated through heat?
4. What result would you expect if the compound bar were made very cold? Try.

From these experiments we see that **solids expand through heat, and some expand more than others.**

2. In Liquids.

Experiment 4.

Fill a flask with water, insert a perforated rubber stopper through which has been thrust a small glass tube open at both ends, and attach a paper scale to the tube as shown in

Fig. 112. Apply heat to the flask and watch the column of water in the glass tube.

1. What is the result?

2. Which expands the more rapidly through heat, water or glass?

3. Prepare another flask and tube identical with the first, filling it with alcohol instead of water. Place the two in the same bath of hot water and watch the result.

It is found that liquids as well as solids expand through heat, and liquids in general expand more rapidly than solids, while some liquids expand more rapidly than others.

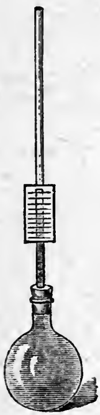


FIG. 112.

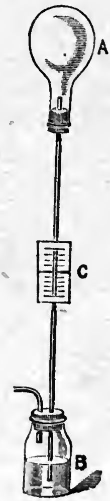


FIG. 112 *a*.

3. In Gases.

Experiment 5.

Arrange apparatus as in Fig. 112 *a*. A is a glass flask filled with air connected by a tube open at both ends with a

bottle B partly filled with water. Apply heat to A and watch the end of the tube below the surface of the water in B.

1. What is the result?

2. What does it prove?

3. Allow A to cool and watch the water. What follows?

4. What does this result prove?

We find that **gases expand very rapidly through heat.**

QUESTIONS.

1. A glass stopper stuck in the neck of a bottle may be loosened by subjecting the neck to violent friction by means of a string. Explain.

2. Pipes of cast iron for conveying steam or gas, if of considerable length, must have expansion joints. Explain the reason.

3. Why does a blacksmith heat a waggon tire before adjusting it to the wheel?

4. The rate at which a clock runs depends on the length of its pendulum. Would you expect it to keep accurate time both in summer and in winter?

5. If a large leaden bullet is cast in a mould a small cavity is found near its centre. What is the reason of this?

6. Why must the water used in Experiment 1, page 108, be taken at the temperature of the room?

7. What variation in the experiment would permit the use of water at any temperature?

8. Why are the rails on a railroad track not laid quite close together?

9. Why is the tone of a piano not the same in a cold as in a warm room?

CHAPTER XVII.

TEMPERATURE.

Experiment 1.

Heat a piece of iron in the flame of a Bunsen burner and drop it into a small vessel containing cold water.

1. What change takes place in the water?
2. What change takes place in the iron?
3. When do these changes cease?

When two bodies, like the iron and the water above, are in such a condition that on being brought together one gains heat while the other loses it, they are said to be at different temperatures. The body gaining heat is said to have a lower temperature than the one losing heat. If two bodies are brought together and neither gains heat from the other, these bodies are said to have the same temperature. Hence we may say that **temperature is the condition of a body considered with reference to its power of receiving heat from or communicating heat to another body.**

I.—Designation of Temperature.

We can describe a particular temperature only by reference to another temperature taken as a standard, that is, by stating by how much this particular tempera-

ture is higher or lower than the standard temperature. Thus we require a **standard temperature** and also a **unit of difference of temperature.**

1. Standard Temperature.

The most convenient standard temperature is the temperature at which ice melts. This temperature is easily obtained by mixing ice and water, and is constant under ordinary conditions. It is usually called the **freezing-point.**

2. Unit of Difference of Temperature.

The unit of difference of temperature used is a fraction of the difference between the temperature of melting ice and the temperature of the steam rising from water boiling under the average pressure of the air at the sea-level (the boiling point). Two units are in use, viz., the **Fahrenheit degree,** which is $\frac{1}{180}$ of this difference, and the **Centigrade degree,** which is $\frac{1}{100}$ of the same difference.

1. How many Fahrenheit degrees are equal to one Centigrade degree?

2. How many Centigrade degrees are equal to 36 Fahrenheit degrees?

3. A temperature 108 Fahrenheit degrees above the freezing point is how many Centigrade degrees above the freezing point?

4. A temperature 15 Centigrade degrees above the freezing point is how many Fahrenheit degrees below the boiling point?

5. Which has the higher temperature, a body 40 Centigrade degrees above the freezing point or a body 100 Fahrenheit degrees below the boiling point?

6. What is the difference between the two temperatures above?

II.—Determination of Temperature—Thermometer.

If you place your hand in contact with a body at a very low temperature you experience a sensation which leads you to say that the body is cold, and if you place it in contact with a body at a much higher temperature you experience a sensation which leads you to say that the body is warm or hot. But your heat sense does not enable you to determine the temperature of a body with any degree of accuracy.

Experiment 1.

Prepare three beakers of water A, B, and C. Make A as hot as you can bear to hold your hand in, make C very cold by putting in ice if necessary, and make B such a temperature that it feels neither hot nor cold. Hold a finger of your right hand in A and one of your left hand in C for one or two minutes. Now immediately put both fingers in B.

1. How does B feel to your right hand?
2. How to your left hand?
3. Is B hot or cold?

This experiment clearly shows that our estimation of the temperature of a body by means of our heat sense depends very much upon the temperature of that part of our own body used in making the estimation.

Experiment 2.

Place your hand in contact with a large piece of iron in a moderately warm room, and with the same hand touch a piece of wood in the same room.

1. If both the iron and the wood have been in the room for a long time, and hence have been for some time in contact with the same air, have the iron and the wood different temperatures?

2. Do you experience the same sensation on touching them?

3. Which feels the colder?

From this experiment it is seen that our estimation of the temperature of a body by means of our heat sense depends on the material of the body as well as upon its temperature. Therefore for various reasons we cannot depend upon the heat sense for the accurate determination of temperature.

Change of temperature in a body is accompanied by other changes, and by observing some of these we may indirectly determine the temperature. Any instrument constructed to thus enable us to estimate the temperature of a body is called a **thermometer.** Of all the changes accompanying change of temperature, change of volume is generally the most convenient for estimating change of temperature, since it can be observed by means of our sense of sight, perhaps the most exact of all our senses.

3. Mercury Thermometer—Construction.

Procure a glass tube of very fine uniform bore, blow a bulb on one end, and a funnel on the other (Fig. 113). Pour some mercury in the funnel and gently heat the bulb. The air expands and a part of it bubbles out through the mercury in the funnel. Allow the bulb to cool. The air pressure on the surface of the mercury in the funnel forces some of the mercury through the tube into the bulb. Now heat the bulb above the flame of a Bunsen burner until the mercury

boils long enough to expel all the remaining air. As the bulb cools the mercury vapour will condense and mercury will run down the tube and completely fill the bulb and tube. Again heat the bulb, and the contained mercury will expand, causing some to overflow at the open end of the tube. While the mercury is overflowing, direct a blow-pipe flame upon the open end and seal it up, at the same instant removing the bulb from above the flame.

The instrument now contains a fixed mass of mercury, which is free to contract or to expand within certain limits, and the construction is such that a small change in the volume of the liquid is easily observed.

FIG. 113.

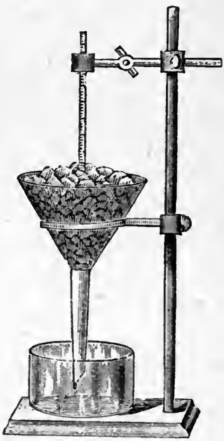


FIG. 114.

4. Finding the Freezing Point.

On a convenient support place a funnel, fill it with snow or melting ice, and place in it the bulb of your thermometer, as shown in Fig. 114. The mercury, contracting faster than the glass, will drop down the tube. When the mercury ceases

to fall, indicating that its temperature is no longer changing, and hence that it has reached the temperature of the melting ice, mark with a file on the tube the position of the upper surface of the mercury.

5. Finding the Boiling Point.

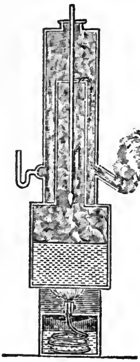


FIG. 115.

Next expose the bulb and tube to the steam rising from pure water boiling under a pressure of 760 mm. of mercury, as in Fig. 115, taking care that the bulb is not plunged into the water, but remains suspended above it. Mark with a file on the tube the termination of the mercury column.

6. Graduation.

Having thus marked the freezing and the boiling points, the next thing is to graduate the instrument.

If you wish to make a Fahrenheit thermometer, mark the freezing point 32° and the boiling point 212°, and divide the intervening portion of the stem into 180 equal parts, extending the graduations above the boiling point and below the freezing point. If you wish to make a Centigrade thermometer, mark the freezing point 0° and the boiling point 100°, and divide the intervening portion of the stem into 100 equal parts, extending the graduations as in the previous case. In Fig. 116 both methods of graduation are represented.

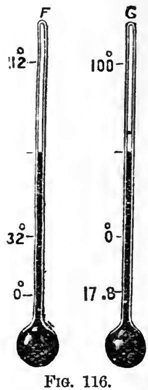


FIG. 116.

1. Why is it necessary that the bore of the tube should be of uniform size throughout?

2. Why should the bore be very small?

7. Comparison of Scales.

1. What temperature on the Centigrade scale is the same as 0° (zero) on the Fahrenheit scale?

2. What temperature on the Centigrade scale is the same as 100° on the Fahrenheit scale?

3. How many Fahrenheit degrees above freezing point is 41° on the Fahrenheit scale (41° F.)? How many Centigrade degrees then is it? What is its reading on the Centigrade thermometer?

4. How many Centigrade degrees is 10° C. from the freezing point? How many Fahrenheit degrees is it? How many Fahrenheit degrees is it from the Fahrenheit zero? What is its reading on the Fahrenheit scale?

5. Find the Fahrenheit readings corresponding to the following Centigrade readings: 12°, 75°, −10°, −40°.

6. Find the Centigrade readings corresponding to the following Fahrenheit readings: 60°, 180°, −5°, −30°.

7. The temperature of a room is T° C. What is its reading on the Fahrenheit scale?

8. The temperature of a room is T° F. What is its reading on the Centigrade scale?

9. Hence state a rule for transforming a reading from the Fahrenheit to the Centigrade scale.

10. What temperature on the Fahrenheit scale is the same as —273 on the Centigrade scale?

8. Alcohol Thermometer.

For the determination of very low temperatures a thermometer filled with alcohol instead of mercury is made use of, as alcohol does not freeze except at an exceedingly low temperature.

9. Air Thermometer.

The apparatus of Experiment 5, page 159, may be used as a thermometer, the position of the water in the tube being an indication of the volume, and hence of the temperature of the air in the flask A. This instrument is very delicate, since a slight change in the temperature of a mass of air is accompanied by a very considerable change in its volume, if the pressure to which the air is subjected remains unchanged.

The fact that the reading of an air-thermometer is influenced by the pressure of the surrounding atmosphere prevents its use for ordinary purposes.

10. Differential Thermometer.

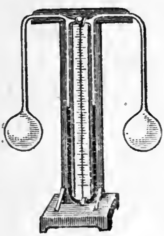


Fig. 117.

For determining slight differences of temperature between two neighbouring points the instrument represented in Fig. 117 is often used. In it two bulbs are connected by a bent tube, the lower part of which is filled with some blue coloured liquid so arranged that both extremities are at the same level when the two bulbs are at the same temperature.

What will be the position of the extremities of the liquid if the right hand bulb is warmer than the left?

III.—Maximum Density of Water.

Experiment 1.

Fill a flask with water at 10° or 20° C., and insert a perforated rubber stopper through which have been thrust a glass tube open at both ends and a thermometer. Press down the stopper until the water rises a few inches in the tube. Take care that no air is caught in the flask. Place the flask in a vessel containing a mixture of ice and salt as in Fig. 118. Watch the thermometer and also the column of water in the tube.

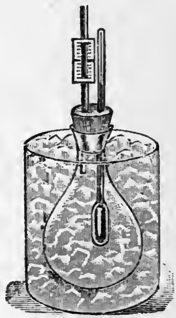


FIG. 118.

1. What change do you observe in the temperature of the water in the flask?

2. What change do you observe in the volume of the water?

3. Does the water continue to contract as its temperature falls?

4. At what temperature has the water its least volume?

5. What change of volume takes place when the water begins to freeze?

The experiment shows us that **a mass of water has its least volume and therefore its greatest density** at **4° C.** It is a matter of common observation that **water expands in freezing.**

IV.—Relation Between the Volume and the Temperature of a Gas—Charles' Law.

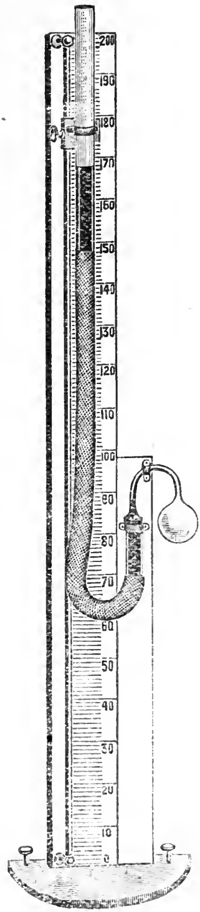


FIG. 119.

Experiment 1.

Arrange apparatus similar to that used in demonstrating Mariotte's Law, page 123, Experiment 1; but instead of the tube closed with a stopcock, use one of the form shown in Fig. 119. The glass bulb may be of any size, but the stem should be of narrow bore. Remove the rubber tube from the stem and, holding its free end on a level with the middle of the sliding tube, fill it with mercury. Now fill the bulb with dry air, attach the rubber tube to the stem, and fasten the stem to the support. Place the bulb in melting ice and so adjust the sliding tube that the mercury stands at a fixed point in the stem. Take the reading (H) of the barometer

$$H = \quad ?$$

Observe the difference in level (H_1) between the mercury in the stem and in the sliding tube.

$$H_1 = \quad ?$$

Then the pressure (P_1) to which the air in the bulb is subjected is

$$P_1 = H \pm H_1$$

and the temperature of the air is 0° C.

Now place the bulb in boiling water and again so adjust the sliding tube that the mercury stands at the fixed point in the stem; that is, by changing the pressure, make the air

enclosed in the bulb assume the same volume as when the bulb was in melting ice. Observe the difference in level (H_2) between the mercury in the stem and in the sliding tube.

$$H_2 = \quad ?$$

Then the pressure (P_2) to which the air in the bulb is now subjected is

$$P_2 = H \pm H_2$$

and the temperature of the air is 100° C.

Suppose V to be the volume of the air in the bulb in both cases.

Since the volume of a gas is inversely proportional to its pressure (Mariotte's Law), this air will occupy a volume of,

$$V \times \frac{P_2}{P_1} \text{ that is } V \times \frac{H \pm H_2}{H \pm H_1}$$

at pressure of P_1. That is, when the pressure remains the same (P_1), the volume of the air changes from V to

$$V \times \frac{H \pm H_2}{H \pm H_1} \text{ or by } V \times \frac{H \pm H_2}{H \pm H_1} - V$$

units of volume for a change in temperature from 0° to 100° C.

Therefore for a change of 1° in temperature the volume will be changed by

$$\frac{V \times \frac{H \pm H_2}{H \pm H_1} - V}{100} \text{ units of volume}$$

$$\text{or by } \frac{V \times \frac{H \pm H_2}{H \pm H_1} - V}{100} \times \frac{1}{V}$$

of the original volume at 0°.

If the experiment is performed with great care this fraction will be found to be about $\frac{1}{273}$.

If the bulb is filled with different gases and put into baths of different temperatures, and changes in temperature noted and observations similar to the above made, it will be found that **the volume of a given mass of any gas at constant pressure increases for each rise of temperature of 1° C. by a constant fraction (about $\frac{1}{273}$) of its volume at 0° C.**

This is generally known as Charles' Law.

11. Absolute Temperature.

If the volume of a given mass of any gas, at a constant pressure, increases for each rise in temperature of 1° C. by $\frac{1}{273}$ of its volume at 0° C., and the pressure of the given mass of gas, at a constant temperature, varies inversely as its volume, then its pressure is increased $\frac{1}{273}$ of the pressure at 0°C. for every degree its temperature is increased, or at 273° its pressure is double of what it is at 0°. *If the pressure were to continue to diminish at the same rate,* at − 273° C., the gas would exert no pressure on the containing vessel. The pressure of the gas is supposed to be due to the impacts of its molecules upon the surface upon which it is said to press (Art. 9, page 53), and therefore when it exerts no pressure its molecules must be supposed to be at rest and the gas to be therefore at its lowest possible temperature. Hence − 273° C. is called **absolute zero.** Temperature reckoned from this point is called **absolute temperature,** that is, the absolute temperature = centigrade reading + 273°.

From a consideration of the above it will be seen that Charles' law may be stated as follows:

12. Charles' Law.

The volume of a given mass of gas at a constant pressure varies directly as the absolute temperature.

QUESTIONS.

1. If the absolute temperature of a gas is doubled and the pressure kept constant, what change takes place in (*a*) its mass, (*b*) its volume, (*c*) its density?

2. If the pressure of a gas is doubled and its volume kept constant, what change may take place in (*a*) its mass, (*b*) its density, (*c*) its absolute temperature?

3. If the pressure of a gas is lessened so that it becomes one-half the original pressure, while the temperature is kept constant, what change takes place in (*a*) the volume, (*b*) the density of the gas?

4. If the volume of a given mass of gas is 100 c.cm. at 27° C., what will the volume become at — 23° C. if the pressure is kept constant?

5. If the volume of a given mass of gas is 1 litre at a temperature 0° what will be its volume at a temperature of (*a*) 100° C., (*b*) — 13° C., the pressure remaining constant?

6. At what temperature will a gas, the volume of which is 1 litre at a temperature of 0° C., become 1200 c.cm. in volume, the pressure remaining constant?

7. What change will be produced in the pressure of a gas by changing its temperature from 0° C. to 273° C., the volume remaining constant?

8. What will be the volume of a mass of air measuring 1 litre at 0° C., if the temperature is raised to 273° C. and the pressure doubled?

9. A closed tube filled with air at 0° and under atmospheric pressure is gradually heated. If the tube can safely stand a pressure of 4 atmospheres, to what temperature may it be heated ?

10. Find the volume at 27° C. and under a pressure of 760 mm. of mercury, of a mass of air which, at 45° C. and under a pressure of 1500 mm., occupies 10 c. ft.?

Since the volume varies directly as the absolute temperature, and the temperature is reduced from 45° C. to 27° C. the volume will be reduced and become

$$\frac{273+27}{273+45}=\frac{300}{318} \text{ of the original volume}$$

when the pressure remains constant ; but since the volume varies inversely as the pressure, and the pressure is reduced from 1500 mm. to 760 mm. of mercury the volume will be increased and become

$$\frac{1500}{760} \text{ of the original volume.}$$

Hence the volume required will be

$$\left(10\times\frac{300}{318}\times\frac{1500}{760}=\right) \text{ c. ft.}$$

11. The volume of a certain mass of gas at a temperature of 17° C., and under a pressure of 600 gm. per sq. cm. is 1000 c.cm.; what will be its volume at a temperature of 27° C. and under a pressure of 1000 gm. per sq. cm.?

12. A mass of gas occupies a volume of 22.4 litres at the temperature 10° C. when the barometer stands at 70 cm., what volume will it occupy at the temperature 0° C. when the barometer stands at 76 cm.?

13. To what temperature must a gas be heated in order that its volume may become double of what it is at 20° C. ?

14. A litre of hydrogen weighs 0.0896 gm. at 0° and 760 mm. barometric pressure. Find the weight of a litre at 20° C. and 766 mm. pressure.

15. The density of air at 0° C. and 760 mm. pressure is 1.29 grams per litre. What is its density at 273° C. and 1000 mm. pressure?

CHAPTER XVIII.

CHANGE OF STATE.

I.—Solid to Liquid and Liquid to Solid.

1. Fusion.

Experiment 1.

Partly fill a large vessel with water at a high temperature, say 90° C., and in it place a small vessel partly filled with water at a low temperature, say 10° C., and place a thermometer in each. Observe the changes of temperature in the two vessels for a minute or two. Now fill the smaller vessel with wet snow or finely broken ice at 0°, and observe the change of temperature in the two vessels while the snow is melting.

1. What change occurs in the temperature of the water in the large vessel in the first case ?

2. What in the temperature of the water in the small vessel ?

3. Which body loses heat ?

4. Where does this heat go ?

5. What does this heat do ?

6. What change takes place in the temperature of the water in the large vessel in the second case ?

7. What in the temperature of the contents of the small vessel ?

8. Does a change of any kind take place in the contents of the small vessel ?

9. Which body loses heat ?

10. Where does it go ?

11. What does this heat do ?

Experiment 2.

Heat a thin glass tube about 5 mm. in diameter and draw it out into a fine thread, as shown in Fig. 120. Heat some

FIG. 120.

paraffin wax in a test-tube and by suction draw some of the liquid paraffin into the fine part of the tube. Close the point by fusing the extremity in the flame. Allow the paraffin to solidify, and fasten, by means of a rubber band or thread, the tube to a chemical thermometer (Fig. 121). Place the tube and thermometer in a beaker of water, and gradually warm the water. Stir the water constantly and notice its temperature when the paraffin in the thin tube melts. Allow the water to cool and note the temperature at which the paraffin solidifies.

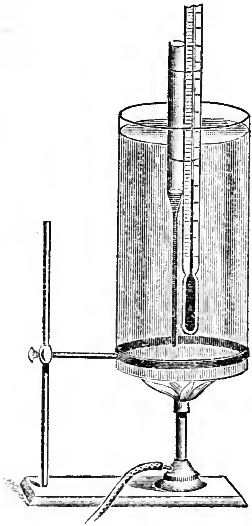


FIG. 121.

1. At what temperature does the paraffin melt?

2. At what temperature does it solidify?

3. Find the melting points of other bodies in the same way.

4. How do their melting points compare with their points of solidification?

2. Solidification.

Experiment 3.

Melt some paraffin wax in a beaker, and when it is all melted place the beaker in another vessel slightly larger and

partially filled with cold water. Observe the temperature of the water from time to time.

1. What change takes place in the paraffin ?
2. What change takes place in the temperature of the water ?
3. Is any heat given out by the paraffin while it is solidifying? How do you know ?

3. Laws of Fusion.

The above and similar experiments prove the following laws :—

(1) **A substance begins to melt at a temperature which is constant for the same substance, if the pressure is constant.**

(2) **The temperature of a solid remains unchanged while fusion is taking place.**

(3) **The temperature of solidification is the same as the temperature of fusion.**

(4) **If a substance expands on solidifying, like ice, its melting point is lowered by pressure; if it contracts, like wax, its melting is raised by pressure.**

4. Solution.

Experiment 4.

Partly fill a beaker with water and note the temperature. Measure out two or three grams of ammonium nitrate and note its temperature. Put the ammonium nitrate in the water and stir the mixture with a thermometer.

1. What is the temperature of the water at first ?
2. What is the temperature of the ammonium nitrate ?
3. What temperature does the mixture reach ?
4. What change do you observe besides change of temperature ?
5. What form of energy disappears ?
6. What is the result produced by this energy ?

Experiment 5.

Break some pieces of ice into small fragments and mix with common salt. Place a thermometer in the mixture.

1. What is the temperature of the ice and of the salt before the mixture?
2. What temperature does the mixture reach?
3. What change besides change of temperature takes place?
4. What energy disappears?
5. What result does this energy produce?
6. Does this energy cease to exist?
7. If not, where can it be?
8. If a stone is thrown upwards it moves slower and slower as it rises and at last stops. What has become of the energy due to the velocity with which it started?

II.—Vapourization and Liquefaction.

5. Ebullition.

Experiment 1.

Partly fill a flask with cold water and insert a perforated stopper containing a tube open at both ends, and a thermometer, as represented in Fig. 122. Place the flask over the flame of a Bunsen burner and let it remain until the water has boiled for some time, carefully watching the thermometer meanwhile.

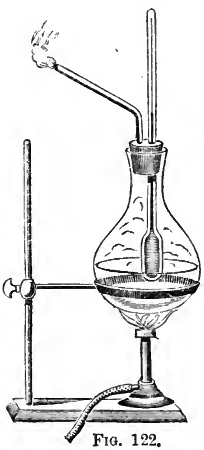


FIG. 122.

1. What change takes place in the temperature of the water at first?
2. Where does the heat come from that effects this change?
3. At what temperature does the water begin to boil?
4. After the water has begun to boil, what change takes place in its temperature?

5. Does the water continue to receive heat after it has begun to boil?

6. If so, what does this heat do?

Experiment 2.

1. With the apparatus shown in Fig. 122 determine (*a*) the temperature of pure water when boiling, (*b*) the temperature of the steam rising from it.

2. Determine these temperatures in the case of water having some common salt in solution.

3. Mix three parts of water with one of alcohol and determine the temperature of the boiling liquid and also of the steam.

4. Sprinkle some iron filings in the flask with pure water and repeat the experiment.

Experiment 3.

Arrange apparatus as in Fig. 123. Heat the water in the flask containing the thermometer until it begins to boil.

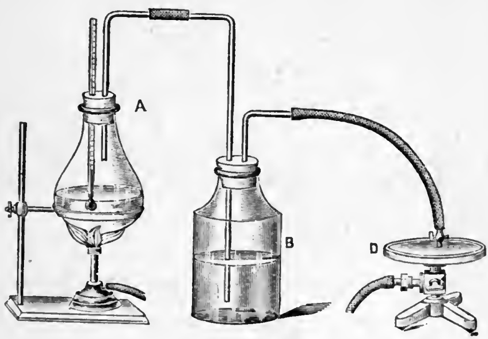


Fig. 123.

Then, removing the lamp, by means of the attached air-pump exhaust the air from the apparatus, thus lessening the pressure on the surface of the hot water.

1. What takes place when you begin to work the air-pump?

2. What change of temperature do you observe?

3. What is the lowest temperature at which you can make the water boil?

Experiment 4.

Half fill a flask with water and boil for a minute or two so that the escaping steam may expel all the air. While it is boiling vigorously, remove the flame and at the same instant close the flask with a rubber stopper. Invert the flask and support it on a retort stand as in Fig. 124. Pour cold water over the flask and watch the result. Now pour very hot water over the flask and see what happens. Again pour cold water over the flask or, still better, immerse the flask in cold water.

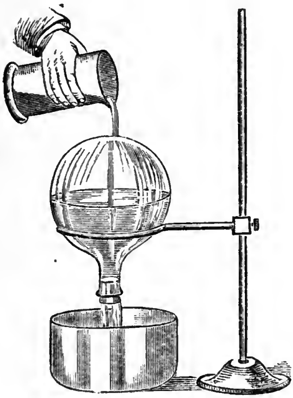


FIG 124.

1. What happens when cold water is first poured over the flask?

2. What when the hot water is poured on?

3. What takes place when the cold water is again poured on, or the flask is immersed in cold water?

4. With a thermometer determine the temperature of the water in the flask at the end of the experiment.

5. What does the flask contain after it has been closed by the stopper?

6. What change in its contents is produced by pouring cold water on it?

7. Can you see any connection between the result of this experiment and that of the previous one?

6. Evaporation.

Experiment 5.

Wrap a piece of muslin about the flask A of the air-thermometer (Fig. 112) and set the instrument in an open window where there is a draught. Pour ether on the muslin drop by drop and watch the result.

1. What becomes of the ether?

2. What change in temperature does the air-thermometer indicate?

Experiment 6.

Pour a few drops of ether on the back of your hand.

1. What change of state takes place?

2. What evidence have you that your hand loses heat?

3. What does this heat do?

4. What effect on the rate of evaporation follows from an increase in the temperature of a liquid, other conditions remaining the same?

5. From which will a given volume of water evaporate more quickly, a narrow deep dish or a broad shallow one?

6. Why do we set the apparatus in a draught in Experiment 5?

The quiet vapourization taking place at the surface of a liquid is called **evaporation.** The **rate** at which evaporation takes place depends upon the nature of the liquid, its temperature, the amount of the vapour of the liquid in the surrounding space, and also the presence in the surrounding space of other gases.

7. Saturation—Dew Point.

The **quantity** of a particular vapour which a given space can hold depends upon the vapour and the temperature, but is independent of the presence of other

gases. A space containing all of a particular vapour which it is capable of holding is said to be **saturated** with that vapour. The temperature at which the water vapour present in the atmosphere would saturate the space it occupies is called the **dew point.**

8. Liquefaction.

Experiment 7.

Prepare the apparatus shown in Fig. 125. Two flasks are connected by a long tube, the greater part of which is surrounded by a much larger tube so arranged that cold water may be made to circulate in the space between the two tubes.

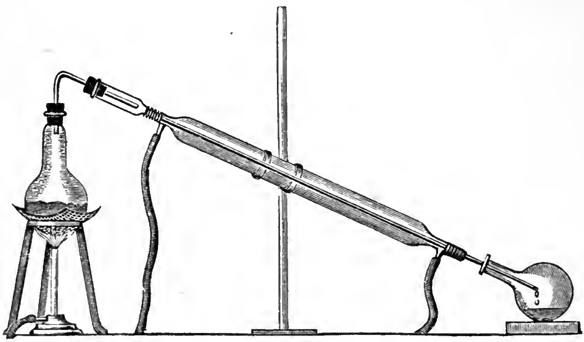


FIG. 125.

Partly fill the higher flask with a mixture of alcohol and water in the ratio of one of alcohol to three of water. Boil the mixture. The steam in passing through the cold tube is condensed, and the resulting liquid is caught in the lower flask. After you have collected a small quantity of liquid in the lower flask, take away the flame. Cool both flasks and

pour part of the contents separately into two evaporating dishes. Try to set fire to the liquids with a lighted match.

1. Are the two liquids the same?

2. Which contains the greater proportion of water?

3. How could you obtain fresh water from sea water?

4. How could you obtain salt from sea water?

5. What change takes place in the temperature of the water used to cool the tube?

6. Whence comes the heat required to produce this change?

These and other experiments establish laws of ebullition as follows:—

(1) **A liquid begins to boil at a temperature which is approximately constant for the same substance if the pressure is constant.**

(2) **The temperature of the boiling liquid remains unchanged until the whole is vapourized.**

(3) **Increase in pressure raises the boiling point of all liquids.**

(4) **The boiling point of water is raised by the presence of salts in solution.**

These experiments also show that heat is expended in changing the state of a body from a solid to a liquid and from a liquid to a vapour, and that heat is produced when the reverse change takes place.

Heat expended in changing the state of a body without changing its temperature is called latent heat.

The heat disappearing in this case is expended in doing work upon the molecules of the body whose state is changed, causing them to occupy positions with respect

to one another different from what their mutual attractions would tend to make them occupy. The molecules, in consequence of occupying such positions, possess potential energy equivalent to the energy expended in giving them these positions, just as a weight raised above the surface of the earth possesses potential energy equivalent to the energy expended in raising it.

QUESTIONS.

1. Why does the temperature generally moderate when snow falls?

2. Does rain bring cool weather or does cool weather bring rain?

3. Why do you feel cooler when sitting in a draught?

4. Why is it difficult to satisfactorily cook food in boiling water at a high elevation above the sea level?

5. Why is an iceberg frequently enveloped by a fog?

6. Why does sprinkling water on the floor have such a cooling effect upon the air of a room?

7. How low a temperature may be determined by means of a mercurial thermometer?

8. Why is one's breath visible on a cold day?

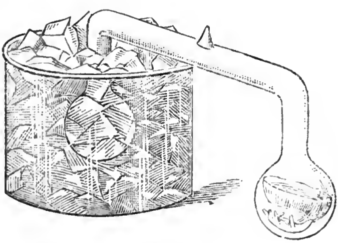


FIG. 126.

9. A tube having a bulb at each end has one of its bulbs half filled with water, the remaining space containing nothing but water vapour. The empty bulb is surrounded by a freezing mixture (Fig. 126), and after a time it is found that the water in the other bulb is frozen. Explain.

CHAPTER XIX.

MEASUREMENT OF HEAT.

I.—Latent Heat.

The temperature of a body and the **quantity of heat** it contains must be carefully distinguished. The former has been defined (page 161) and is a **condition** depending, probably, upon the average energy possessed by each molecule while the latter is a **quantity of energy,** the energy possessed by a body in virtue of the vibrations of its molecules.

1. Heat Unit.

The thermometer enables us to find the temperature of a body, but it does not enable us to determine the quantity of heat possessed by the body. For example, a gram of water at 100° C. has a higher temperature than a kilogram of water at 50° C., but the latter contains a far greater quantity of heat. To measure heat as to measure any other quantity we must select as a unit a quantity of the same kind. The unit in general use is the quantity of heat required to raise the temperature of a unit mass of water one Centigrade degree. We thus have a heat unit corresponding to each unit of mass. **The heat required to raise the temperature of one gram of water one Centigrade degree is called the calorie, and is the unit most frequently used.**

It has been ascertained that the quantity of heat required to raise the temperature of a mass of water 1° is

approximately the same at all parts of the scale between 0° and 100°, hence one way of measuring a particular quantity of heat is to observe by how many degrees this heat will change the temperature of a known mass of water.

1. How many calories will raise the temperature of 25 gm. of water 10 degrees ?

2. How much heat is given out by the cooling in hot water pipes of 100 Kgm. of water from 100° C. to 80° C.?

3. 100 gm. of water at 80° C. are mixed with 40 gm. at 10° C. What is the temperature of the mixture ?

4. A flask containing 500 gm. of water at 10° C. is placed over a steady Bunsen flame, and in five minutes the water begins to boil. How much heat does the flame give up to the flask during one second ?

2. Latent Heat of Fusion of Ice.

Let us determine the amount of heat required to melt one gram of ice.

Experiment 1.

Obtain a thin glass beaker that will hold about one litre, wrap it in flannel, and pour into it 500 grams of hot water. Place a thermometer in the water to note its temperature. Weigh out 100 gm. of dry snow or finely broken ice and drop it into the beaker, rapidly stirring the mixture with the thermometer until the snow or ice is all melted. Observe the temperature of the water just as the snow is all melted.

Temperature of water at first	(T) = °?
Temperature of snow at first	= 0°.
Temperature of water when snow is melted	(T_1) = °?

Amount of heat given out by the water in the beaker at first

$$= 500\ (T—T_1)\ \text{calories}$$

This heat melts the snow and raises the temperature of the resulting water from 0° to T_1°.

Amount of heat required to raise from 0° to T_1° the temperature of the 100 gm. of water formed by melting the snow

$$= 100\ T_1\ \text{calories.}$$

Hence amount of heat required to melt the 100 gm. of snow

$$= \{ 500\ (T - T_1) - 100\ T_1 \}\ \text{calories.}$$

Therefore amount of heat required to melt one gram of snow or ice

$$= \frac{500\ (T - T_1) - 100\ T_1}{100}\ \text{calories}$$

$$= \qquad\qquad \text{calories ?}$$

Experiment 2.

Bore a hole in a block of ice, and pour into it 10 grams of water at a known temperature (T°C.), immediately covering the hole with a slab of ice. After a few minutes remove the cover and suck up into a pipette all the water from the hole. Carefully determine the mass of this water.

Mass of water removed (m)	=		grams ?
" " put in	=	10	"
∴ " ice melted	=	$(m - 10)$	"

The 10 grams of water put in are cooled from T° to 0°, and hence the heat lost by this water = 10 T calories.

Therefore the amount of heat required to melt $(m - 10)$ grams of ice without changing its temperature = 10 T calories.

Therefore the amount of heat required to melt one gram of ice

$$= \frac{10\,T}{m - T} \text{ calories.}$$
$$= \quad \text{calories?}$$

The amount of heat required to melt a unit mass of any substance is called the latent heat of fusion of that substance.

Careful experiments show that it requires approximately 80 calories of heat to melt one gram of ice. This fact is usually expressed by saying that the latent heat of fusion of ice is 80.

How should we express the same fact if we were to make our statement with reference to the Fahrenheit degree?

3. Latent Heat of Vapourization of Water.

Let us now find the amount of heat required to change a gram of water into steam without changing the temperature.

Experiment 3.

Pour 500 grams of water into a flask which will hold about one litre. Carefully note the temperature of the water and place the open flask over the flame of a Bunsen burner. Observe the time that elapses before the water begins to boil. Allow the water to boil for ten minutes or more, taking careful note of the time. Weigh the water which remains in the flask.

Temperature of water at first	(T) =	°?
Time required to raise water to the boiling point	(t) =	seconds?
Time during which the water is boiling	(t_1) =	seconds?
Quantity of water remaining	(m) =	grams?

Quantity of heat received from the Bunsen flame in t seconds

$$= 500\ (100 - \mathrm{T})\ \text{calories.}$$

Quantity of heat received from the Bunsen flame in t_1 seconds

$$= \frac{t_1}{t}\ 500\ (100 - \mathrm{T})\ \text{calories.}$$

But this heat evaporates $(500 - m)$ grams of water at 100°. Therefore the quantity of heat required to evaporate one gram of water without changing its temperature is

$$\frac{\frac{t_1}{t}\ 500\ (100 - \mathrm{T})}{500 - m}\ \text{calories.}$$

$$= \qquad\qquad \text{calories?}$$

Experiment 4.

Prepare apparatus as shown in Fig. 127. A is a flask containing water. B is a trap intended to catch any liquid that

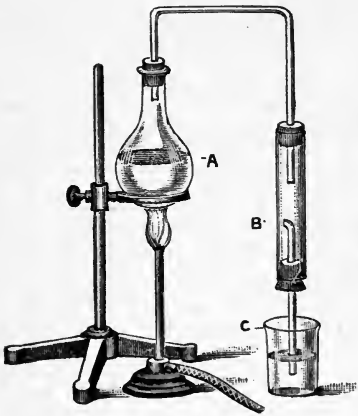


FIG. 127.

may escape from A or may be condensed in the tube. C is a thin glass beaker containing 100 grams of water.

Taking C away apply heat to A until the water in it boils freely and steam is escaping from the open tube. Now carefully note the temperature of the water in C, wrap it in flannel, and place it as shown in the diagram. Keep stirring the water in C with a thermometer, observing the temperature from time to time. Allow the boiling to continue until the water in C has reached a temperature near the boiling point. Carefully note this temperature and immediately remove C. Weigh the water in C.

Temperature of water in C at first (T) = ?
Temperature of water in C at last T_1 = ?
Quantity of water in C at last (m) = grams ?

$(m - 100)$ grams of steam is condensed in C and cooled from 100° to T_1°.

The heat arising from this raises the temperature of 100 grams of water from T° to T_1° and therefore equals

$$100\ (T_1 - T) \text{ calories.}$$

The heat given out by the $(m - 100)$ grams of water resulting from the condensation of the steam in cooling from 100° to T_1° is $(m - 100)\ (100 - T_1)$ calories.

Therefore the heat produced by the changing of $(m - 100)$ grams of steam into water must be

$$\{\ 100\ (T_1 - T) - (m - 100)\ (100 - T_1)\ \} \text{ calories.}$$

Therefore the amount of heat produced by the condensation of one gram of steam is

$$\frac{100\ (T_1 - T) - (m - 100)\ (100 - T_1)}{m - 100} \text{ calories.}$$

$$= \text{calories ?}$$

Experiments such as the above show that the quantity of heat required to change one gram of water into steam without changing the temperature is approximately 537

calories, and that the same quantity of heat is produced when one gram of steam is changed to water.

The quantity of heat required to change a unit mass of any liquid into vapour without changing its temperature is called the latent heat of vapourization of that liquid.

Hence we say that the latent heat of vapourization of water is 537.

Careful experiments show that in all cases the heat which disappears (is rendered latent) when a solid is changed to a liquid, or a liquid is changed to a vapour, again appears as heat when the reverse change takes place.

1. How much heat is required to melt 100 gm. of ice ?

2. How much heat is produced by the liquefaction of 100 gm. of steam ?

3. Ten grams of steam at 100° will melt how much ice at 0° ?

II.—Specific Heat.

4. Capacity for Heat.

Experiment 1.

Pour melted paraffin into a flat circular vessel to the depth of about an inch. After the paraffin has cooled, remove the cake and support it as shown in Fig. 128. Procure a number of balls of different materials, lead, tin, copper, zinc, iron, etc., and of the same mass. Heat the balls to the same temperature in a vessel of boiling

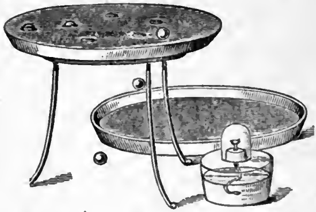


FIG. 128.

water. Taking them from the water, place them on the cake of paraffin and watch the result.

1. What takes place as each ball gives up some of its heat to the paraffin?

2. Are the balls cooled through the same number of degrees before ceasing to give up heat to the paraffin?

3. Is the result the same in all cases?

4. What produces the result in each case?

5. Which ball gives up the greatest quantity of heat in cooling from the temperature of the water bath to that of the paraffin?

The above experiment indicates that equal masses of different substances give out different quantities of heat in cooling through the same range of temperature, but it does not enable us to compare those quantities with any degree of accuracy.

The quantity of heat required to change the temperature of a unit mass of any substance 1° is called the capacity for heat of that substance.

5. The Calorimeter.

To determine accurately the quantity of heat given out by a particular body in cooling through a known range of temperature, an instrument called a calorimeter is used. One form of calorimeter is shown in Fig. 129. It consists of three metal vessels separated from one another by layers of broken ice. A pipe leads from the middle vessel to the outside, through which the water formed by the melting of any of the ice in this vessel will run. The inner vessel is to contain the hot body, and the layer of ice between the outer and middle

vessels is to prevent any of the ice in the middle vessel from being melted by heat from outside. To use this calorimeter, heat the body to be experimented upon to a known temperature, and, removing the covers, drop the hot body into the inner vessel, quickly replacing the covers. As the hot body cools, the heat it gives out goes to melt the ice in the middle vessel, and the resulting water runs out and is collected and weighed.

FIG. 129.

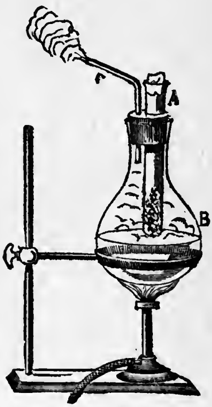


FIG. 130.

Experiment 2.

Prepare the apparatus shown in Fig. 130. In the dry test-tube A place 50 grams of granulated lead. Place a Bunsen burner under the flask and boil the contained water until you are sure that the lead has reached the temperature of the steam (100° C.). Remove the covers from your calorimeter, pour the lead from A into the inner vessel, and quickly replace the covers. Carefully collect and weigh all the water which flows from the middle vessel of the calorimeter.

Instead of using the calorimeter the heated lead may be placed in a hole bored in a block of ice, and covered with a slab of ice. When the lead has ceased to melt the ice it is withdrawn, and the water removed from the hole with a pipette, and weighed.

Mass of water collected (m) = grams?

Hence the heat given out by 50 grams of lead in cooling from 100° to 0° is the heat required to melt m grams of ice $= 80m$ calories. Therefore the amount of heat given out by one gram of lead in cooling one degree is

$$\frac{80\ m}{50} \text{ calories.}$$

$$= \qquad \text{calories?}$$

The ratio of the quantity of heat required to raise the temperature of any mass of a substance 1° to the quantity of heat required to raise the temperature of the same mass of water 1° is called the specific heat of that substance.

Hence the quantity of heat required to change a mass (m gm.) of any substance (specific heat=s) through T° of temperature equals

$$(m\text{Ts}) \text{ calories.}$$

1. What is the specific heat of the lead in the above experiment?
2. Determine the specific heat of zinc, iron, sand, etc.

Experiment 3.

Determine the mass of some shot.

Mass (m) = grams?

Heat the shot in steam to a temperature of 100° as in Experiment 2.

Determine the mass and temperature of some **water**.

Mass (m_1) = **grams?**

Temperature (T_1) = ?

Place the water in a beaker, or better in a thin metal vessel polished on the outside (a lemonade shaker answers well), surround the beaker with some wool or batting.

Pour the shot into the water, stir the two together, and when the two have reached the same temperature determine the temperature.

Temperature T_2 = °?

Heat gained by water $= m_1 (T_2 - T_1)$ calories.

Heat lost by shot $= m (100 - T_2) x$ calories if x is the specific heat of the shot.

But heat lost by shot = heat gained by water,

$$\text{or, } m (100 - T_2) x = m_1 (T_2 - T_1)$$

$$x = \frac{m_1 (T_2 - T_1)}{m (100 - T_2)} = \quad ?$$

II.—Mechanical Equivalent of Heat.

The connection between the unit of heat (energy of molecular vibration) and the unit of mechanical energy (energy of bodily onward motion) is a matter of great

importance. This connection was first accurately determined by Joule, who used the apparatus illustrated in Fig. 131.

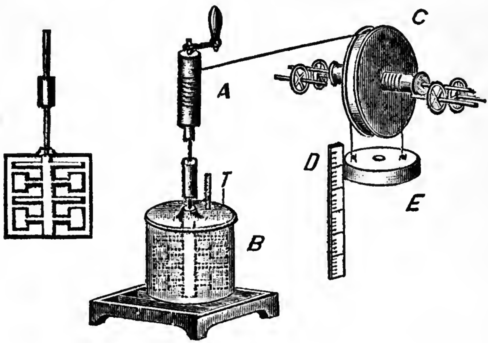


FIG. 131.

B is a copper vessel filled with water and provided with a brass paddle-wheel, arranged somewhat like a churn. This paddle is driven by a falling weight suspended from a roller connected with a pulley C provided with friction-wheels. A cord wound on this pulley passes round the vertical paddle-shaft A. As the weight E falls the paddle revolves and the water in B is heated by friction. A thermometer T indicates the temperature of the water.

With this apparatus Joule learned that the quantity of heat required to raise the temperature of one pound of water one Centigrade degree is the same amount of energy as is expended in raising a mass of 1,390 pounds through a vertical distance of one foot (1,390 foot-pounds).

The value of the heat unit expressed in units of mechanical energy is called the mechanical equivalent of heat.

From Joule's determination as given above calculate the value of the calorie in gram-centimetres.

QUESTIONS.

1. If 10 lbs. of water at 12° C. be mixed with 40 lbs. of water at 90° C., find the temperature of the mixture.

2. Fifty grams of ice are placed in 520 grams of water at 19.°8 C. If the resulting temperature is 10.°5 C., what is the latent heat of fusion of ice?

3. Steam is passed into a mass of 495 grams of water at 15.°2 until the temperature becomes 35.°4. The mass of water and condensed steam is now 512 grams. What is the latent heat of vapourization of water?

4. The latent heat of fusion of ice is 80; find

(*a*) What mass of water at 90° C. will melt 100 grams of ice.

(*b*) What mass of ice must be dissolved in a litre of water at 4° C. to reduce the temperature of the water to 2° C.

(*c*) The resulting temperature when 30 grams of ice are dropped into 100 grams of water at 50° C.

(*d*) The specific heat of brass if a piece weighing 80 grams, heated to 100° C., melts 9 grams of ice when placed in an ice calorimeter.

5. The latent heat of vapourization of water is 537; find

(*a*) The resulting temperature when 25 grams of steam at 100° are passed into 300 grams of ice cold water.

(*b*) How many calories will be required to convert one litre of water at 4° C. into steam at 100° C.

(*c*) How many grams of steam at 100° C. will just melt 10 grams of ice at 0° C.

CHAPTER XX.

TRANSMISSION OF HEAT.

It is a matter of common experience that heat has a tendency to pass from a warmer to a colder body or from a warmer to a colder part of the same body, and that a tendency to equalization of temperature is manifest in all bodies so placed that heat can pass from any one to the others.

We shall now consider some of the modes by which this diffusion of heat takes place.

I.—Conduction.

Experiment 1.

Thrust one end of a copper wire 4 or 5 inches long into the flame of a spirit lamp or Bunsen burner, and hold the other end in the hand. Touch your fingers to points nearer the flame.

1. What evidence have you that heat is being transmitted from the flame to the hand ?

2. What transmits this heat ?

Experiment 2.

Repeat Experiment 1, using instead of the wire a piece of glass rod.

What difference do you observe in the result ?

The heat is said to be transferred by the wire from the flame to the hand by **conduction**, and the wire is said to be a better **conductor** than the glass, which transfers the heat very slowly.

Conduction is the transmission of heat from hotter to colder parts of a body, or from a hot body to a colder one in contact with it without any visible motion of the parts of the bodies.

We have seen (page 37) that whenever two bodies whose velocities are different come in contact with each other there is a transference of energy. Just as the energy of bodily onward motion is transferred when two bodies whose speeds are different come in contact, so the energy of molecular motion, or heat, is supposed to be transferred when two bodies the average energies of whose molecules, that is whose temperatures, are different are made to touch.

We have learned (Experiment 2, page 163) that bodies, which have really the same temperature often appear to have, when touched with the hand, different temperatures. This is due to the relative conducting power of the body in contact with your hand. The intensity of the sensation depends upon the rate at which molecular energy is transferred to or from the hand; and this is dependent on the difference in temperature between the hand and the body when first brought in contact, and upon the conductivity of the body. If a body is a very poor conductor, the film in contact with the hand almost at once reaches the temperature of the hand.

1. Why do iron fixtures appear colder than the wood in a cold room and warmer than the wood in a very hot room ?

2. Silver is a better conductor of heat than the metal of which plated spoons are made. How could you distinguish between a solid silver spoon and a plated one?

3. Why are the handles of (*a*) coffee-pots, (*b*) ice pitchers, made of substances which are poor conductors of heat?

1. Relatative Conductivities of Solids.

Experiment 3.

Take rods of copper, glass, iron, bone, etc., and place one end of each in a beaker containing boiling water. Allow them to stand for a few minutes and touch the fingers to the exposed ends.

Which are good conductors and which bad?

Experiment 4.

Take a rectangular vessel (Fig. 132), and pass through openings closed with perforated corks, rods of different substances, say copper, brass, iron, lead, glass, and wood, all of the same diameter and length. Coat the portions outside the opening with a thin layer of paraffin wax, and fill the vessel with water kept at the boiling point by means of lamps placed under the vessel. When the line of separation between the melted and unmelted parts of the wax on each rod no longer moves along the rod, measure the length of the melted portion on each rod.

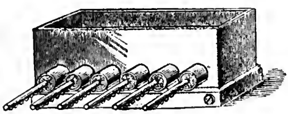


FIG. 132.

1. Arrange the substances of which the rods are made in the order of their conductivities.

2. Which are usually the better conductors, metals or non-metals

2. Practical Applications.

Experiment 5.

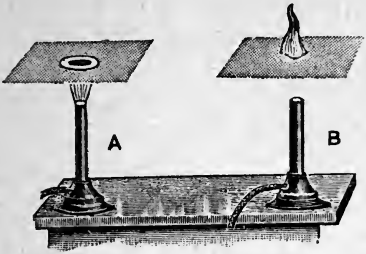


FIG. 133.

Depress upon the flame of a spirit lamp or Bunsen burner a piece of fine wire gauze, as shown in Fig. 133 A.

1. What effect has it upon the flame?

2. Is there any gas above the gauze?

To answer this question apply a lighted match above the gauze.

Experiment 6.

Hold the gauze about half an inch above the gas burner, turn on the gas and light it above the gauze (Fig. 133 B).

Does the flame pass through the gauze?

The explanation of the phenomena observed in the last two experiments is that the metal of the gauze conducts away the heat so rapidly that the gas on the side of the gauze opposite the flame is never raised to a temperature sufficiently high to light it.

FIG. 134.

Advantage is taken of this principle in the construction of the Davy safety-lamp for miners who have to enter mines containing combustible gases. It consists of jacket of wire gauze enclosing a lamp. Fig. 134 shows the construction of one of these lamps.

3. Conductivity of Liquids.

Experiment 7.

Fill a test-tube nearly full of water and hold it in an inclined position, as shown in Fig. 135, so that the flame from a spirit lamp or Bunsen burner may strike the upper part of the tube just below the surface of the water.

Fig. 135.

1. Is the heat transferred rapidly or slowly to the lower part of the tube?

2. Is water a good or a bad conductor of heat?

The conductivity of liquids is, as a usual thing, much lower than that of solids.

Name some liquid which is an exception to this law?

4. Conductivity of Gases.

Air and other gases are poorer conductors of heat than liquids. The low conductivity of porous bodies, such as cloth, feathers, sand, etc., is in a great measure due to the air which they contain.

II.—Convection.

5. Mass-Transference of Heat.

Experiment 1.

Repeat Experiment 7 above, heating the tube at the bottom and holding it at the top.

1. How does your observation in this case differ from that in the above experiment?

2. How is the heat transferred from the lamp to the upper layers of the water?

To answer this question perform the following experiments:

Experiment 2.

Fill a small flask with boiling water which has been coloured with some aniline dye or ink, cork it, and, without inverting it, place it at the bottom of a pail filled with cold water. Remove the cork.

1. What takes place?
2. What is the reason?

To answer this question consider

(*a*) Which is the denser, the hot water placed at the bottom or the cold water surrounding it?

(*b*) According to the laws of buoyancy (page 112), should the pressure of the cold water cause the hot water to rise or to sink?

Experiment 3.

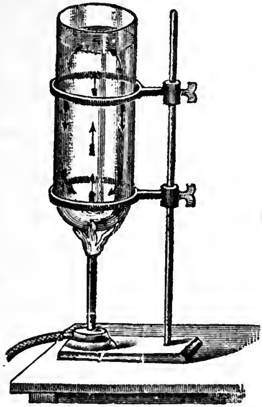
Repeat Experiment 2, introducing the mouth of the inverted flask just below the surface of the water and removing the cork with as little agitation of the cold water as possible.

1. How do your observations differ from those in the case of Experiment 2?

2. What is the reason for the difference in the phenomena?

Experiment 4.

Fill a large beaker nearly full of water, add a few crystals of aniline dye or potassium permanganate, and heat by applying the flame of a spirit lamp or Bunsen burner to the centre of the bottom of the beaker (Fig. 136).



1. Does the water in the upper part of the beaker become warmed?

2. If so, how has the heat been transferred from the lamp?

To answer this question observe the currents formed in the water

Vary the experiment by applying the flame at other points of the beaker.

1. From what point do the upward currents always start?

2. Trace the directions of the return currents.

Currents set up in a fluid on account of the unequal temperatures of its parts are called **convection currents,** and the transference of heat from one point to another by transferring the matter containing it is called **convection.**

6. Convection Currents in Liquids.

The above experiments illustrate the action of heat in producing convection currents in the mass of liquids. The following experiment shows how a continuous current may be kept up in tubes by the same action.

Experiment 5.

Arrange apparatus as shown in Fig. 137. The upper vessel A may be made by cutting the bottom from a bottle. B is a large flask and C and D glass tubes. The perforated corks should be rubber. Fill the apparatus with water, taking care that no air be left in the flask B. Place some aniline

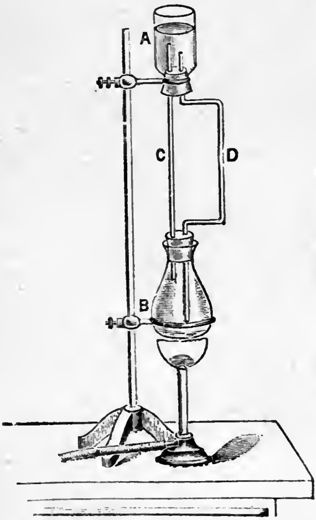


Fig. 137.

dye in the upper vessel. Apply heat to the bottom of the flask B.

1. Describe the circulation of the water in the tubes and in the vessels.

2. Explain the reasons for this circulation.

3. What would happen if the tube C were pushed down and its lower end brought to the bottom of the flask B?

7. Practical Applications.

By a circulation similar to that illustrated in Experiment 5, buildings are heated by a system of hot water pipes. Fig. 138 shows the way in which the pipes are connected and the direction of the circulation. The boiler A, filled with water, is

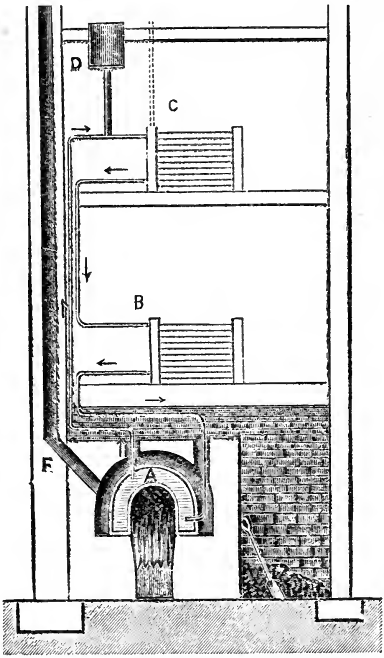


Fig. 138.

heated by a furnace in the basement of the house. The upper part of the boiler is connected by means of a pipe with an expansion tank D, placed in the top of the building. Another pipe passes downward from the expansion tank through coils B and C in the rooms to be heated and enters the boiler near its base.

8. Convection Currents in Gases.

Experiment 6.

Make some touch paper (paper that will burn without flame and give off a great quantity of smoke) by dipping paper in a saturated solution of potassium nitrate (saltpetre) and then drying it.

Light some of the paper and hold it above the flame of a candle, or better, above the chimney of a burning lamp.

1. What are the directions of the air currents which the smoke renders apparent?

2. What is the cause of these currents?

Experiment 7.

Make a wooden or metal box of the form shown in Fig. 139. The front should be a pane of glass which slides into its place through grooves. Cut two holes in the top of the box and over each hole place a lamp chimney. Remove the front, light a candle, place it under one of the chimneys in the position shown in figure, and replace the front. Light some touch paper and hold it over the other chimney.

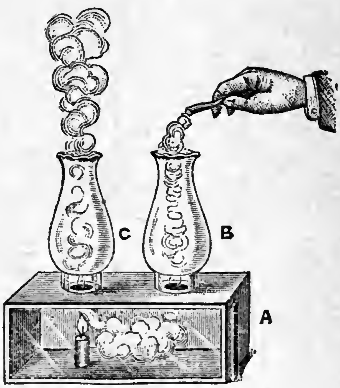


FIG. 139

Describe and explain the currents of air observed.

Close the chimney B with your hand.

1. What happens after a short time?

2. Explain the reason.

Experiment 8.

Place a lighted candle in a large glass jar (a candy jar answers well), and insert a perforated cork into which glass tubes are placed in the positions shown in Fig. 140.

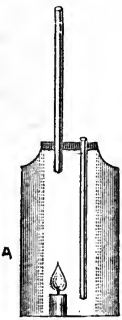


FIG. 140.

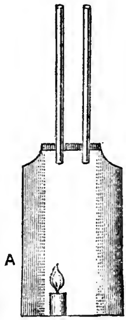


FIG. 141.

1. Does the candle continue to burn?

2. If so, explain how fresh air is supplied to it and how the products of combustion are removed from the jar.

Draw the right hand tube up to the position shown in Fig. 141. Observe the burning of the candle for a short time.

What takes place? Explain the reason.

9. Ventilation.

Experiments 7 and 8 illustrate the modes of producing air currents, and show the necessity of providing a means of ingress as well as egress to any confined space in which the air is being vitiated. The air of dwelling houses is vitiated by the respiration of those living in them and by the combustion of the oil or gas used for lighting. Means of removing the foul air and bringing in fresh air should be provided. The production of convection currents is the simplest expedient. This principle is taken advantage of in the heating and the ventilating of buildings by warm air furnaces. Fig. 142 shows a system of heating and ventilating rooms in which a number of persons are required to

remain for a considerable time. The air comes from the outside through the fresh air opening into the fresh air room, passes over the furnace, is heated, and ascends through the warm air tube into the rooms. After circulating through a room and heating it, the air passes through vents in the wall into foul air spaces under the floor and down through a duct into the foul air

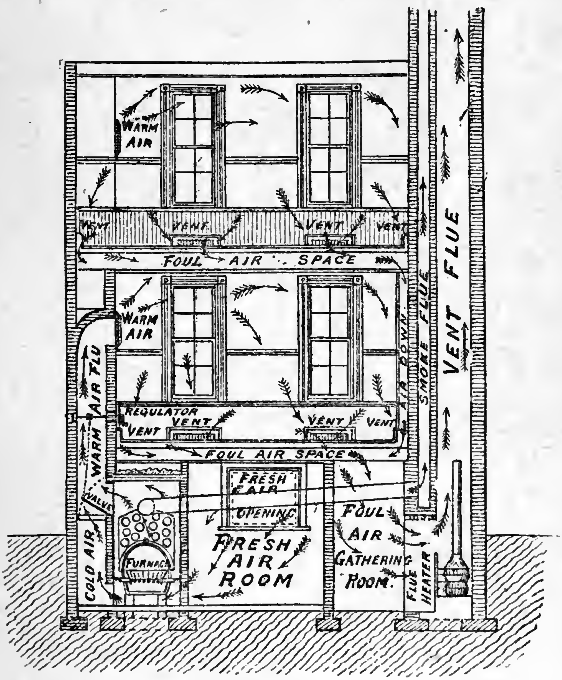


Fig. 142.

gathering room. From this it is taken to the outside of the building by a vent flue, in which an upward draught is maintained by means of the heat which it receives from the hot smoke flue placed alongside of it.

The air passages are so arranged that a part of the cold air from the fresh air room may pass through a valve directly into the warm air flue without passing over the furnace, the quantity of this air being regulated by a regulator connected with the valve. In this way the temperature at which the air enters the room is under control. In summer, when the furnace is not in use, the circulation, for the purpose of ventilation, is maintained by keeping the vent flue hot by means of a small stove or a flue heater kept burning at its base.

10. Convection Currents in Nature.

Winds are the result of convection. Different parts of the earth's surface become unequally heated, and air currents are consequently set up. Their directions depend mainly on the position of the heated belts and the rotation of the earth.

Ocean currents are to a certain extent the result of convection, but these are also influenced by the action of the prevailing winds.

III.—Radiation.

Experiment 1.

Heat an iron ball to a high temperature and place at a distance of a foot or two from it and on a level with it, the bulb of an air thermometer or one of the bulbs of a differential thermometer (Fig. 143).

1. What change in temperature does the thermometer indicate?

2. Is this change in temperature due to a change in the temperature of the surrounding air?

To answer this question interpose a screen of glass or tin between the ball and the thermometer.

What do you observe?

The heat is said to be transmitted from the hot ball to the thermometer by **Radiation.** In the same way heat is transmitted to bodies in a room from a hot stove or from an open fire, and from the sun to the earth. This transmission is independent of the air as it takes place in the most perfect vacuum we can produce. To explain the phenomena of radiation it is found necessary to suppose *that a medium, called ether, pervades all space and penetrates between the molecules of all ordinary matter, which are embedded in it and probably connected with one another by its means.*

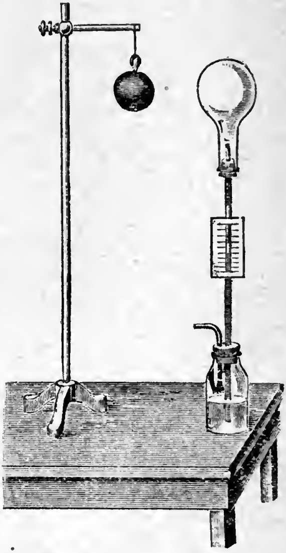


FIG. 143.

The vibrating molecules of a hot body communicate their motion to the ether which surrounds them, and thus cause vibrations to be set up in the ether. These vibrations by a species of wave motion pass from the heated body in all directions through the ether, and may, on reaching any body of matter, communicate their energy to its molecules, and it in turn is heated.

The transmission of heat then by **radiation consists in the transformation of the energy of molecular vibration, or heat, into the energy of ether vibration, or**

radiant energy; and the retransformation of radiant energy into heat.

The first transformation is generally called **Emission**, the second **Absorption.**

10. The Emissive Power of a Body.

Our most common experiences teach us that the emissive power of a body—that is its power to transform heat into radiant energy—varies with its temperature. A hot stove radiates more heat than a cold one. But the emissive power does not depend on the temperature alone.

Experiment 2.

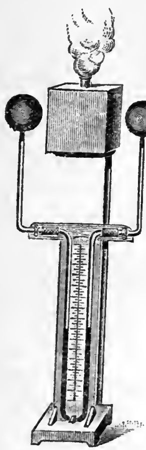


Fig. 144.

Blacken the bulbs of a differential thermometer by smoking them over a candle flame, turn them up as shown in Fig. 144. Blacken one of the faces of a cubical tin box about four or five inches wide, fill it with boiling water and place it midway between the bulbs, with the blackened surface facing one of the bulbs and the opposite bright surface facing the other bulb.

1. At what temperature is each of the surfaces of the cube?

2. Which bulb of the thermometer absorbs the most radiant energy?

3. Which surface, the blackened or the bright one, has the highest emissive power?

Repeat the experiment, roughening with sand-paper one of the surfaces, and leaving the opposite one polished.

Which has the higher emissive power, the polished surface or the roughened one?

Experiment 3.

Take two small tin cans of the same size furnished with lids, cut a hole in each lid through which a stirrer and a thermometer can be inserted. Blacken the outside of one and polish that of the other. Pour the same quantity of water heated to the same temperature (70° or 80° C.) into each, and place them on some non-conducting material. Stir the water in each can at intervals and take the temperature.

1. Which can loses heat the more rapidly?
2. Which has the higher emissive power?

The emissive power of a body depends upon

1. **Its temperature.**
2. **The nature of its surface.**

Dull, black surfaces have the highest emissive power and bright polished ones the lowest.

11. Absorptive Power.

Experiment 2.

Place an iron ball heated to a high temperature (Fig. 145) midway between the bulbs of a differential thermometer, one bulb of which is blackened, the other covered with tinfoil.

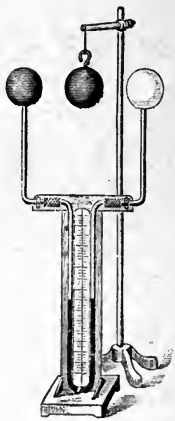


FIG. 145.

1. What change do you observe in the liquid levels?

2. In which bulb is the more radiant energy transformed into heat?

This experiment and others of the kind show that a body whose emissive power is high possesses great absorptive power, or that, as it is generally stated, **good radiators are good absorbers.**

12. Diathermancy or Transmissive Power.

Bodies which allow radiant energy to be transmitted through them without much increase in their temperatures are said to be diathermanous. Rock salt is one of the most diathermanous of solid bodies. Air is also fairly diathermanous, but water vapour is not.

1. How will the presence of water vapour in the air affect the quantity of the earth's heat changed into radiant energy during any particular interval ?

2. When will the surface of the earth at any particular place cool the more rapidly, on a clear or on a cloudy evening ? Why ?

No body is perfectly diathermanous, nor is any body a perfect absorber. Most bodies exercise what is called selective absorption. For example, glass allows the radiant energy from a highly heated body, like the sun, to pass, but absorbs the radiant energy emitted by a red hot ball or by an open fire.

13. Reflection of Radiant Energy.

Bright polished bodies are as a usual thing neither diathermanous nor good absorbers. The greater part of the radiant energy falling upon them is reflected from their surfaces and sent back into space without transformation. **Good reflectors are poor absorbers and good absorbers poor reflectors.**

Since there can be no loss of energy, the total amount of radiant energy falling on a body equals the amount reflected + the amount absorbed + the amount transmitted by the body.

Radiant energy becomes known to us not only by its transformation into heat, but also by its power of exciting the nerves of the eye and awakening in the brain the sensation of light. It is by means of radiant energy that we see objects.

The theory of selective absorption, the laws of reflection, and other phenomena connected with radiant energy will be discussed under Light. See Part II.

QUESTIONS.

1. Why is it that if boiling water is poured into a thick glass tumbler it breaks, while if the water is poured into a thin glass vessel it does not break?

2. A piece of paper held in the flame of a lamp will burn, yet the paper may be held in the lamp flame without igniting if it is wrapped around a cylinder of brass. Explain. What would happen if a wooden cylinder were substituted for the brass one? Why?

3. If a copper kettle is filled with cold water and placed over a gas flame, the flame shrinks away from the kettle and does not come in contact with its bottom. Explain the reason.

4. Why is flannel a good substance of which to make clothes to keep our bodies warm, and also a good substance to wrap around a block of ice to keep it from melting?

5. Why are (*a*) ice houses constructed with double walls; (*b*) double windows used in houses in winter?

6. Why, in freezing ice cream, is the freezing mixture put in a wooden vessel and the cream in a metal one?

7. Water may be boiled in a paper box placed over a lamp flame without burning the paper. Explain the reason. Make the experiment. The paper pails used by oyster dealers will answer.

8. Formerly to ventilate a mine two shafts were provided at opposite ends of the mine and a fire kept burning at the bottom of one of the shafts. Explain the air currents set up.

9. What is the source of the heat given out by the Gulf Stream to the British Isles? Trace its transmission.

10. What effects are produced upon the climate of a place and upon the variations of temperature in it by the presence of a large body of water near it? Explain the reason.

11. Should a kettle intended to be heated by standing in front of a fire be bright or black? Give reasons for your answer.

12. The earth absorbs and radiates heat more quickly than the water. In what direction A or B (Fig. 146) will the air move (*a*) during the day, (*b*) during the night? Explain the cause of land and sea breezes.

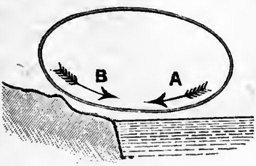


Fig. 146.

13. Should soot be allowed to collect on the bottom of a kettle used in heating water over a flame? Should the remaining part of the kettle be kept bright or dull? Give reasons.

14. Explain the advantages of silver plating the outside of a calorimeter.

15. The bulbs of two identical thermometers are coated, the one with lamp black, the other with silver; compare their readings (*a*) when in a water bath (*b*) when exposed to the direct rays of the sun, (*c*) when exposed on a clear night. Explain why they do not agree on all these occasions.

16. A Norwegian cooking box consists of a wooden box having a thick lining of felt inside, so arranged as to leave a central space into which the vessel containing the food is placed. The food is partially cooked, placed in the box, and covered over with the lid. Why will the cooking be completed in the box?

17. A building is heated with hot water pipes. Explain fully how the heat is transmitted from the furnace of the boiler to a person in the building. What would be the effect on the temperature of some distant part of the building of coating the pipes near the boiler with (*a*) woollen felt, (*b*) with dull black lead?

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